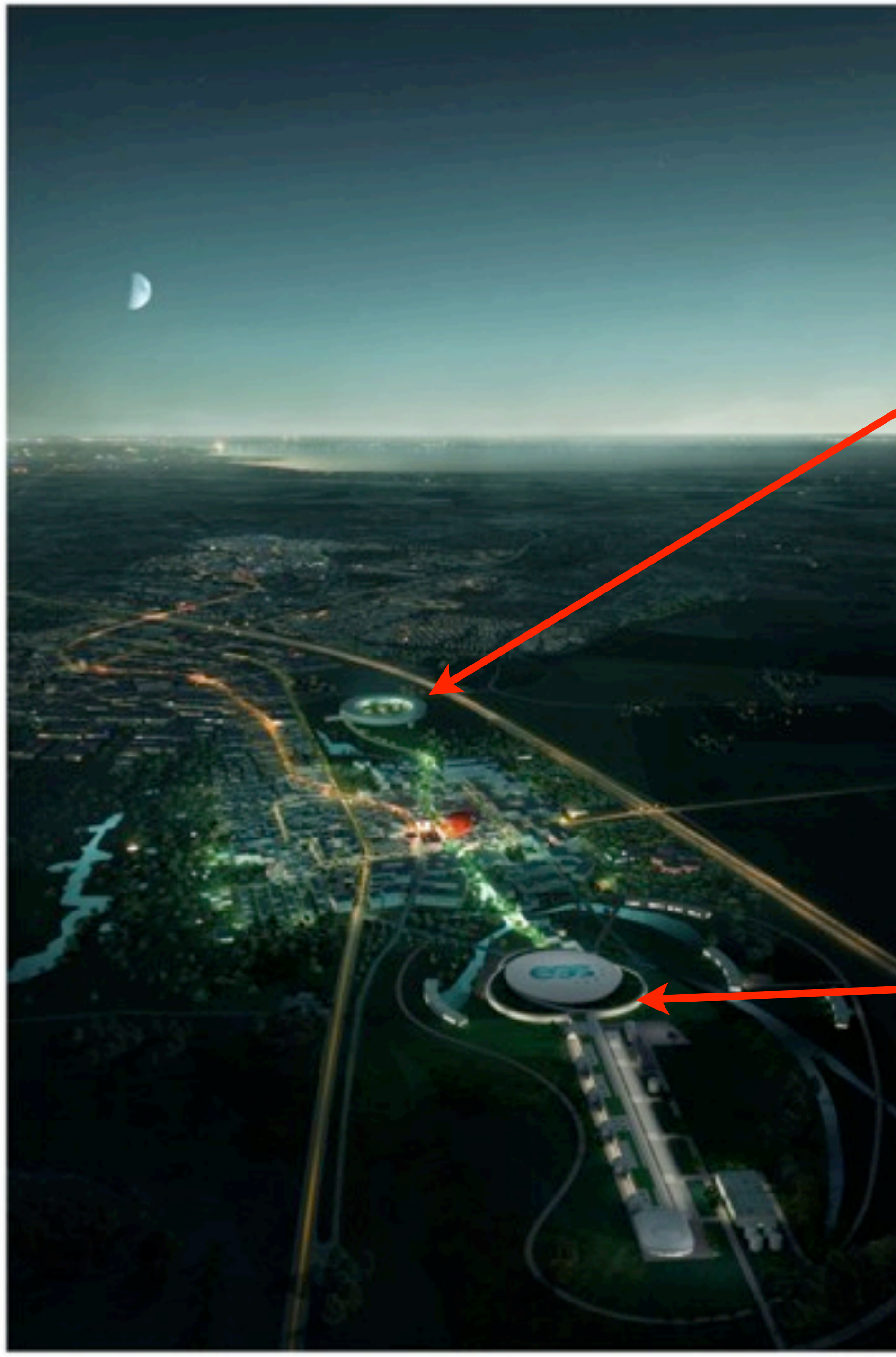
ESS Design & Progress

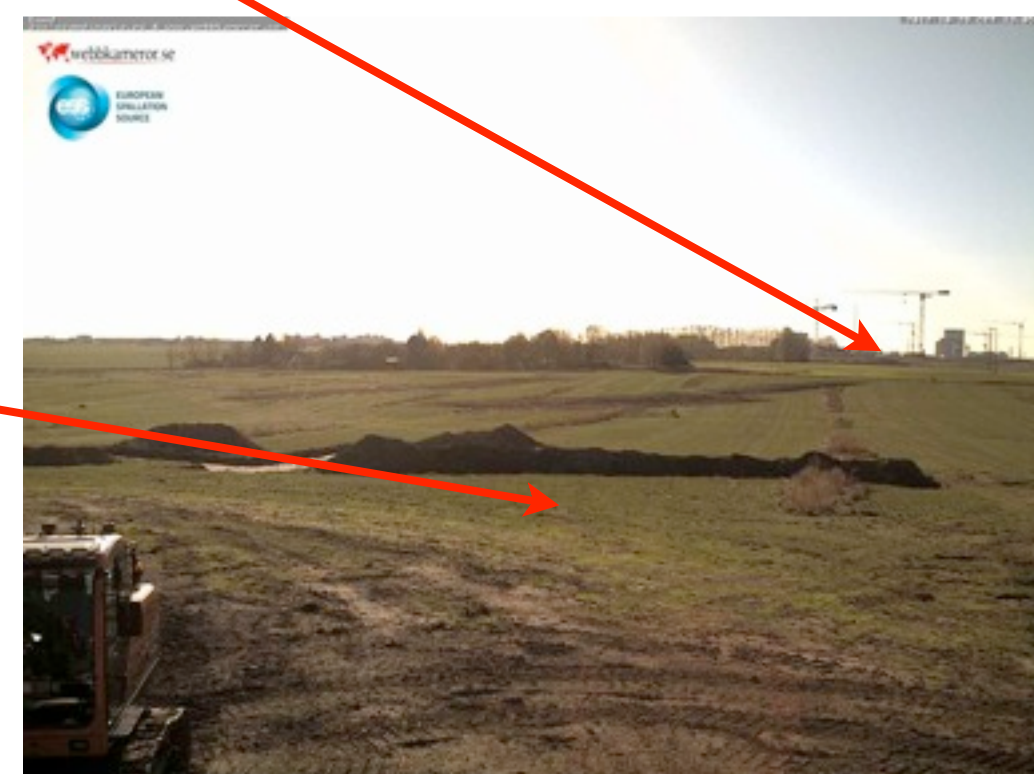
ESS Technical Design Report



Release 3.01

MAX IV

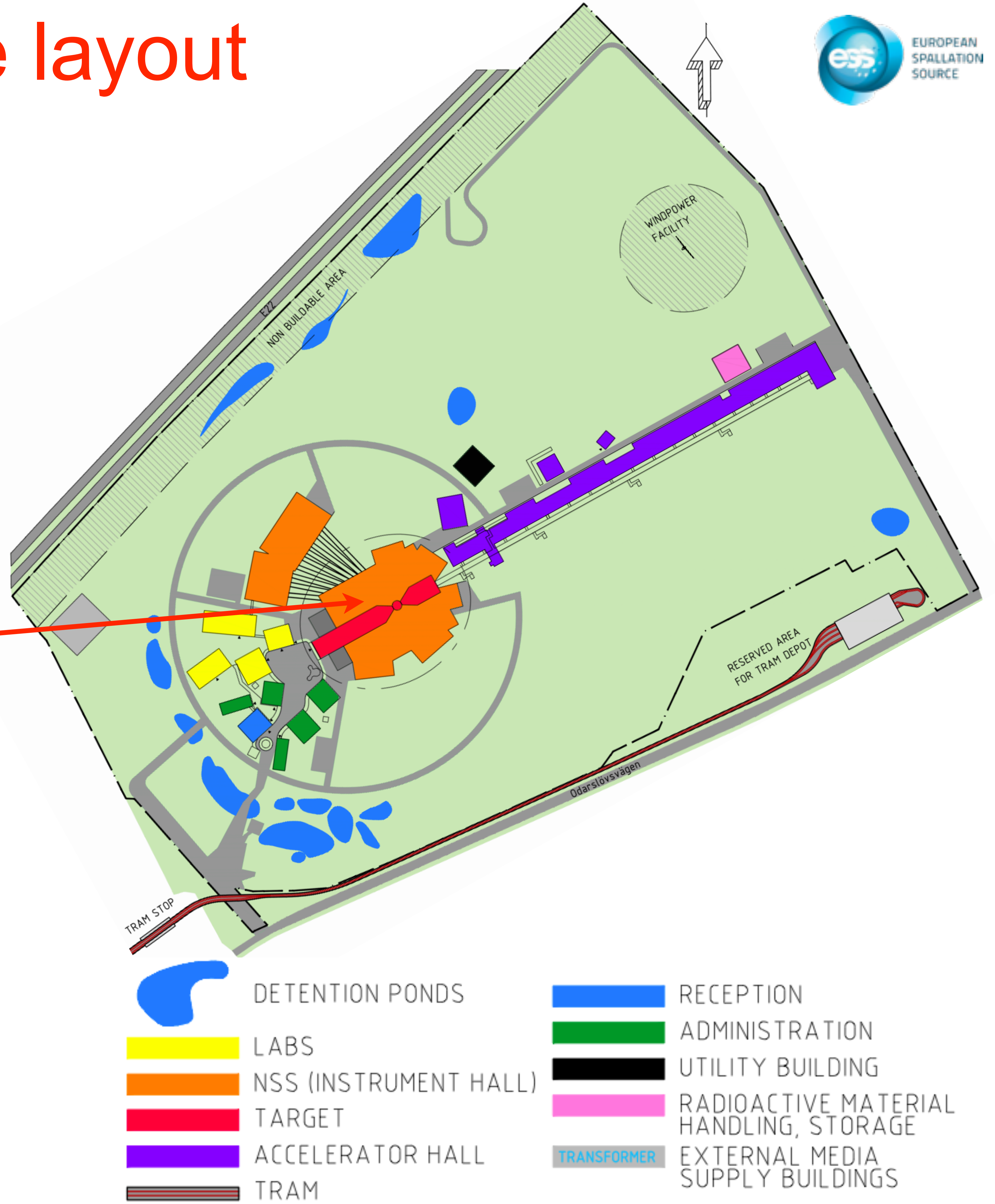
ESS



Preliminary site layout

EUROPEAN SPALLATION SOURCE

The central campus



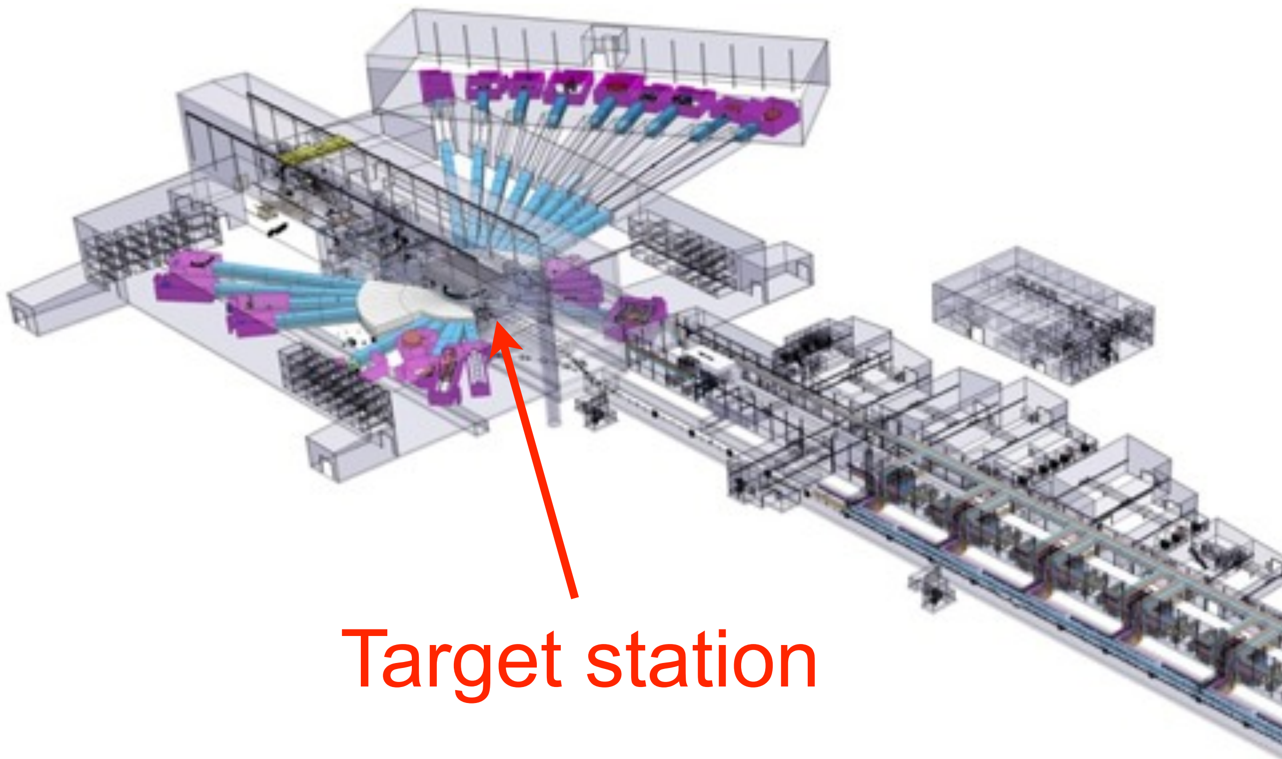
The target station in the background has an “instantly recognisable” overhanging oval roof.

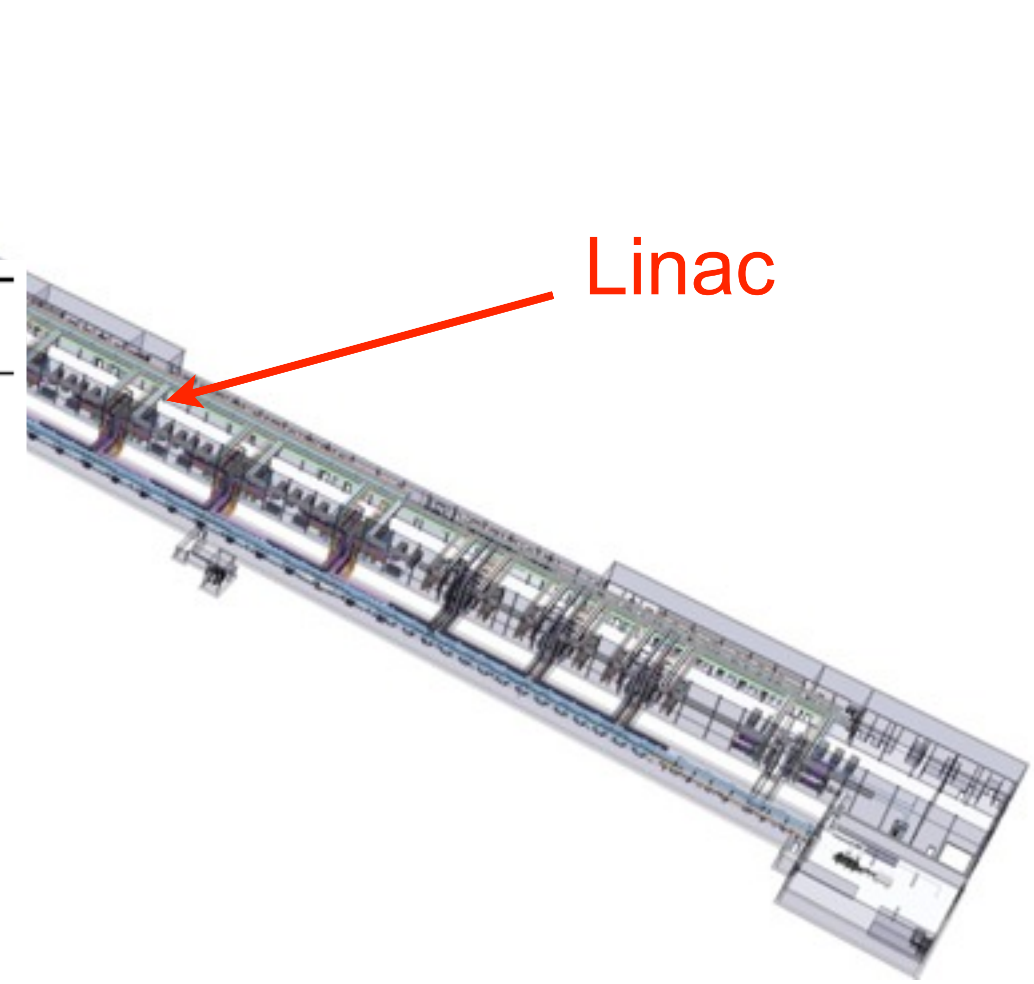
The tram stop behind the viewer connects to Lund train station & city, 5 km away.

Plant layout

The 5 MW rotating tungsten wheel target is cooled by flowing helium gas.

Passive cooling assures safety, even in the event of complete power loss.



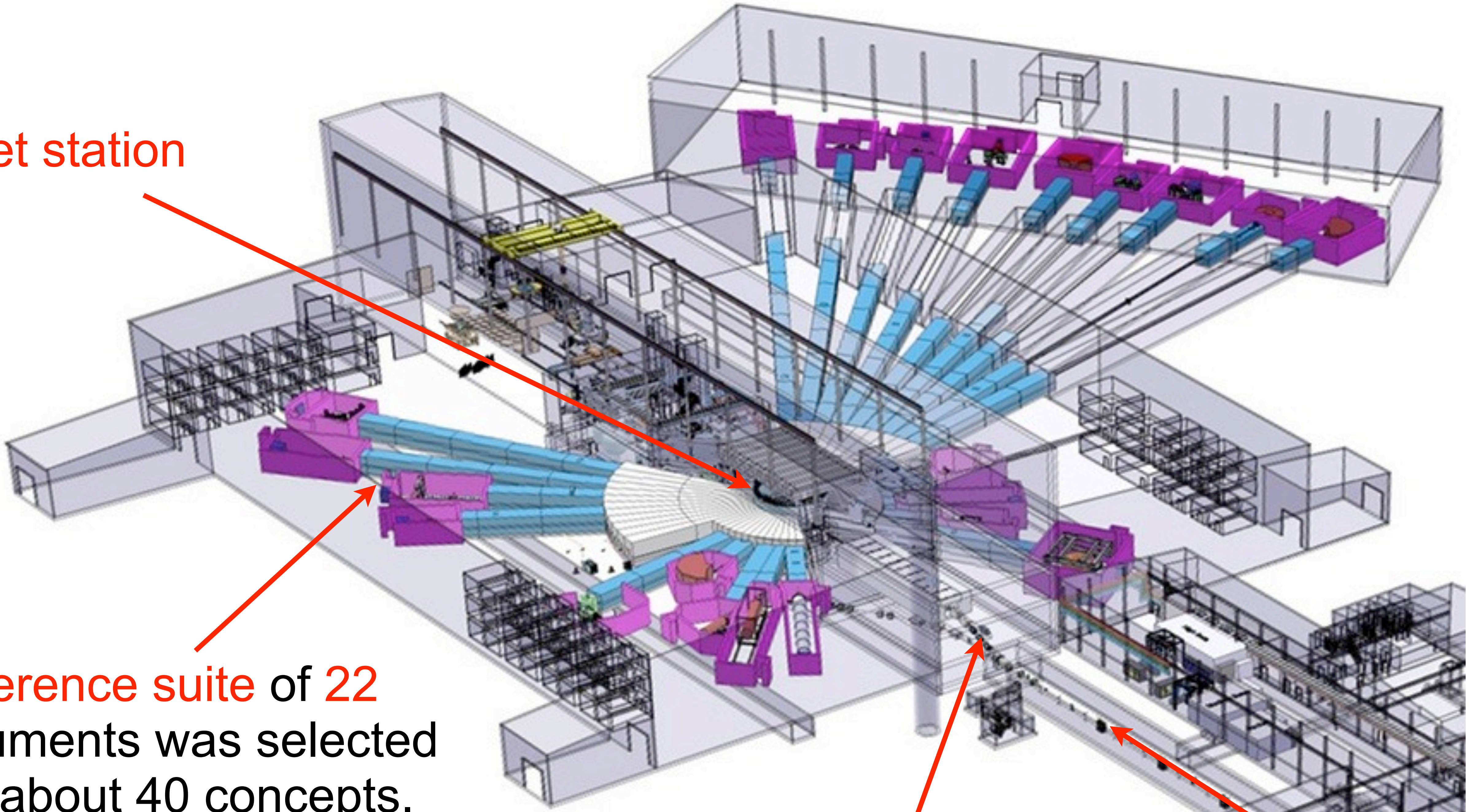


Parameter	Unit	Value
Average beam power	MW	5
Number of target stations		1
Number of instruments in construction budget		22
Number of beam ports		48
Number of moderators		2
Separation of ports	degrees	5
Proton kinetic energy	GeV	2.5
Average macro-pulse current	mA	50
Macro-pulse length	ms	2.86
Pulse repetition rate	Hz	14
Maximum accelerating cavity surface field	MV/m	40
Annual operating period	h	5000
Reliability	%	95

High level parameters

Reference instrument suite

Target station



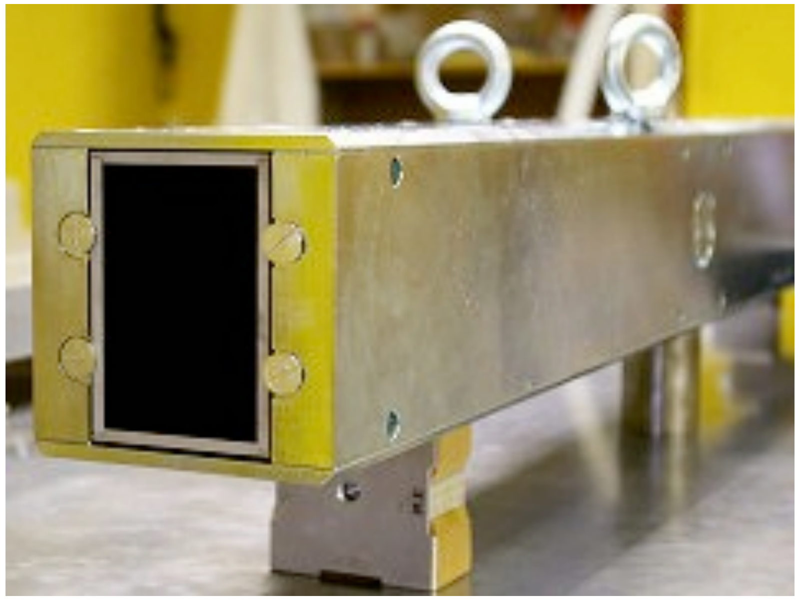
A reference suite of 22 instruments was selected from about 40 concepts.

Two or 3 instruments will be selected every year for construction.

Vertical dog-leg

Protons

Neutron optics - guides & mirrors

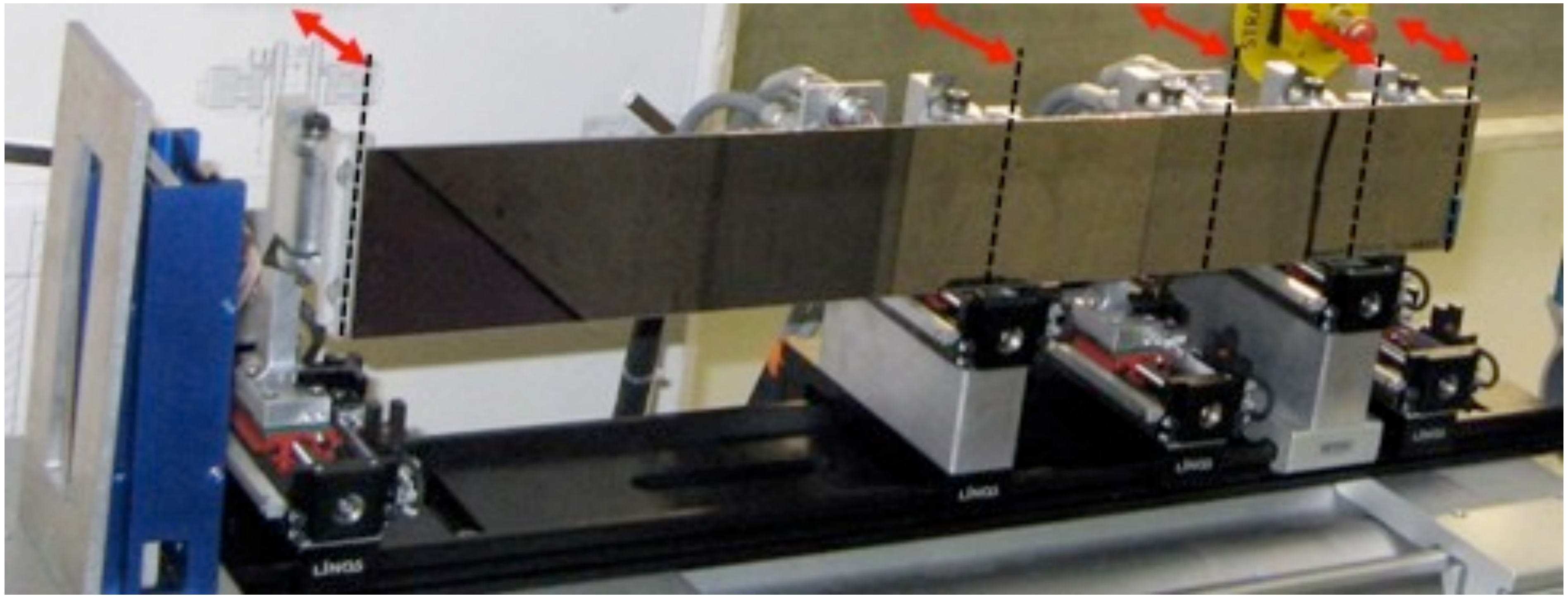


Steel sandwich guides.

ESS instruments make heavy use of multi-layer neutron reflection.

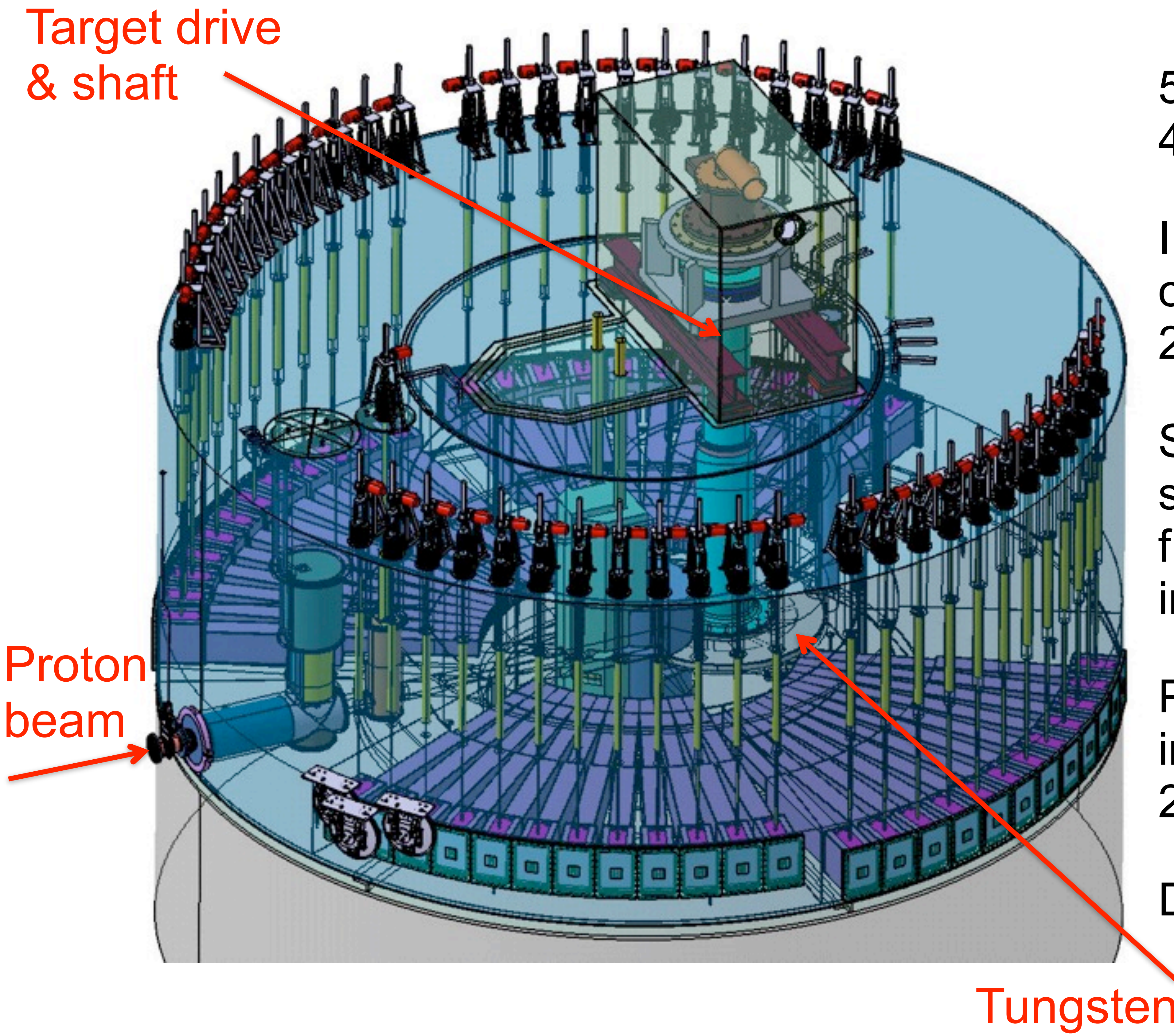
Neutrons are conservative!

In-pile guides in steel shielding.



Adaptive optics: red arrows show actuators that bend the mirror, adjustably focusing the neutrons can for each experiment (PSI).

Monolith & beam extraction



5° separation between 48 beam ports.

Instruments are optimised & laid out at 22 of the beam ports.

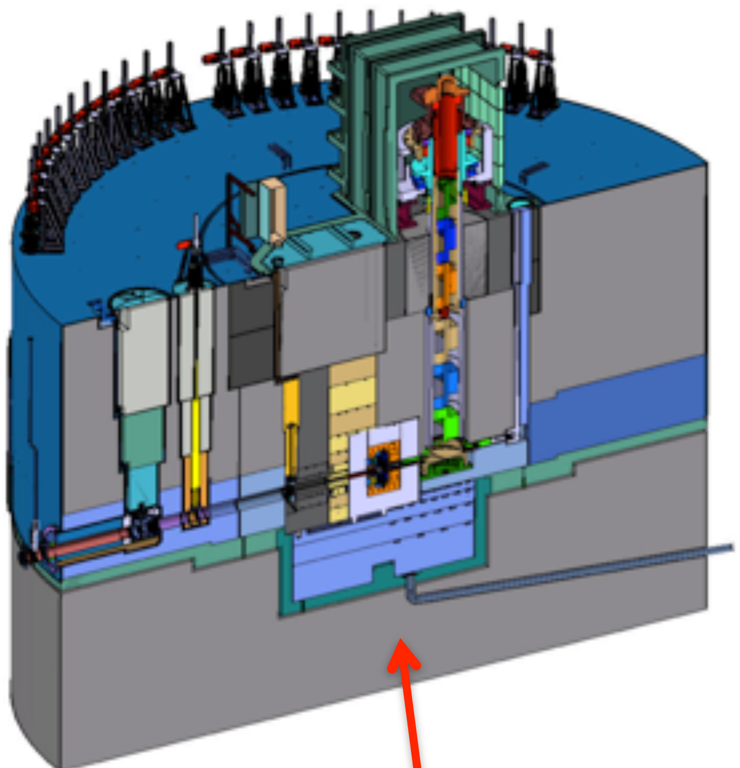
Small angular separation increases flux (~ 20%) & shrinks instrument halls.

Possibility for more instruments after 2025.

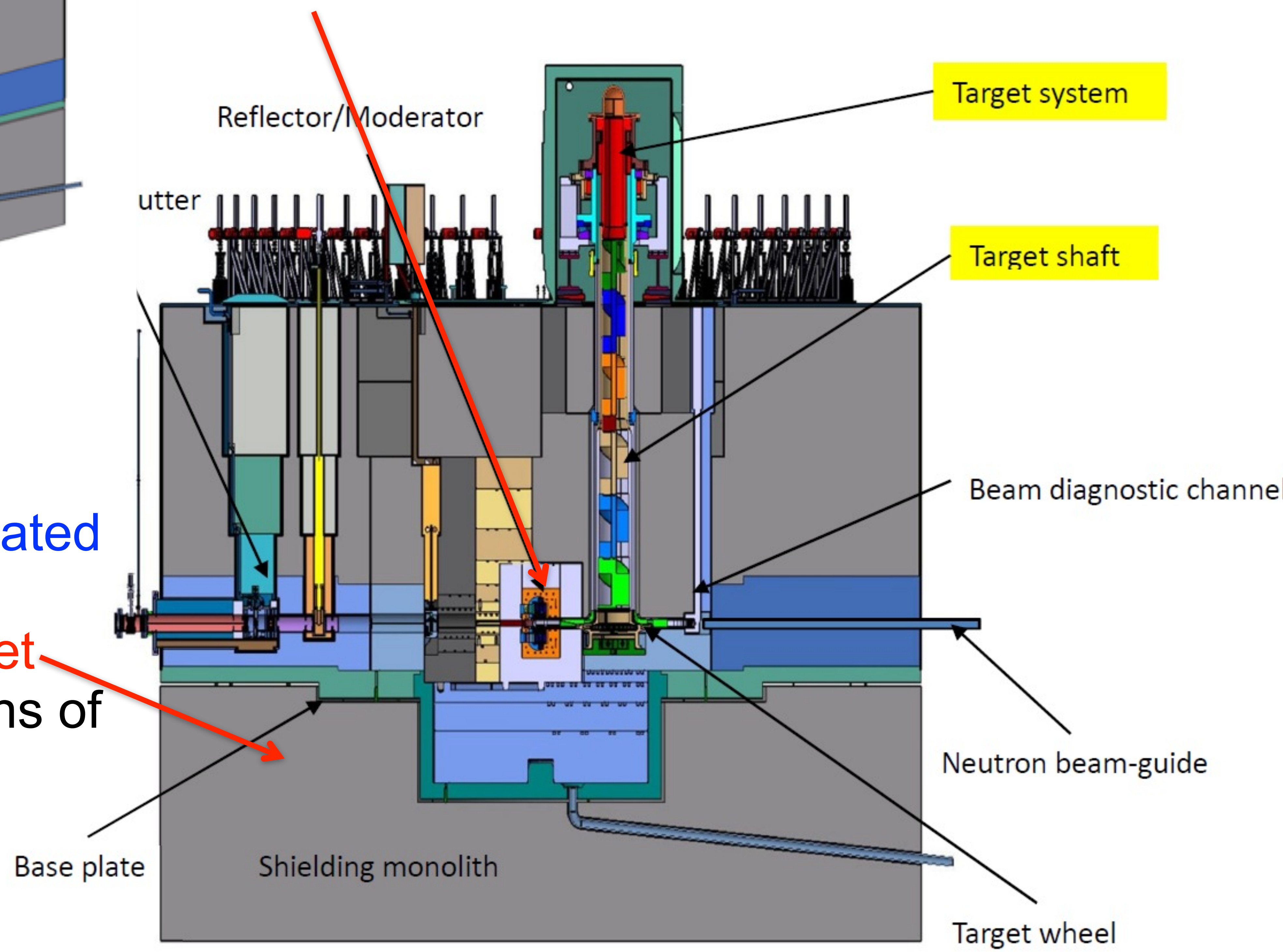
Design freeze 2014.

Monolith & beam extraction

EUROPEAN SPALLATION SOURCE



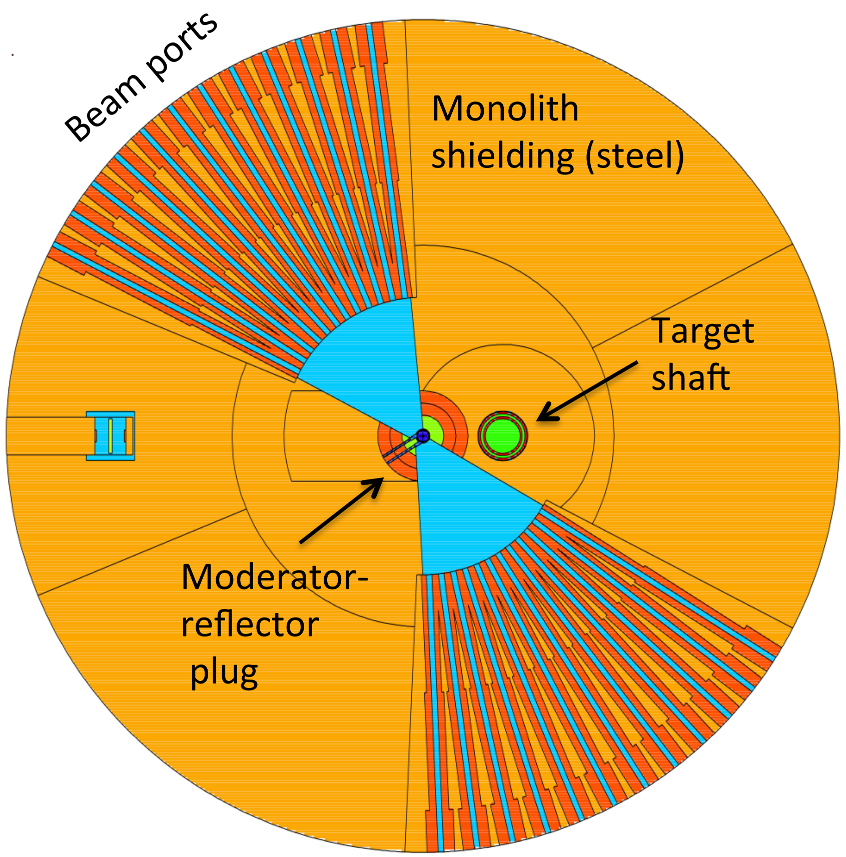
The moderator-reflector system transforms fast neutrons into slow neutrons.

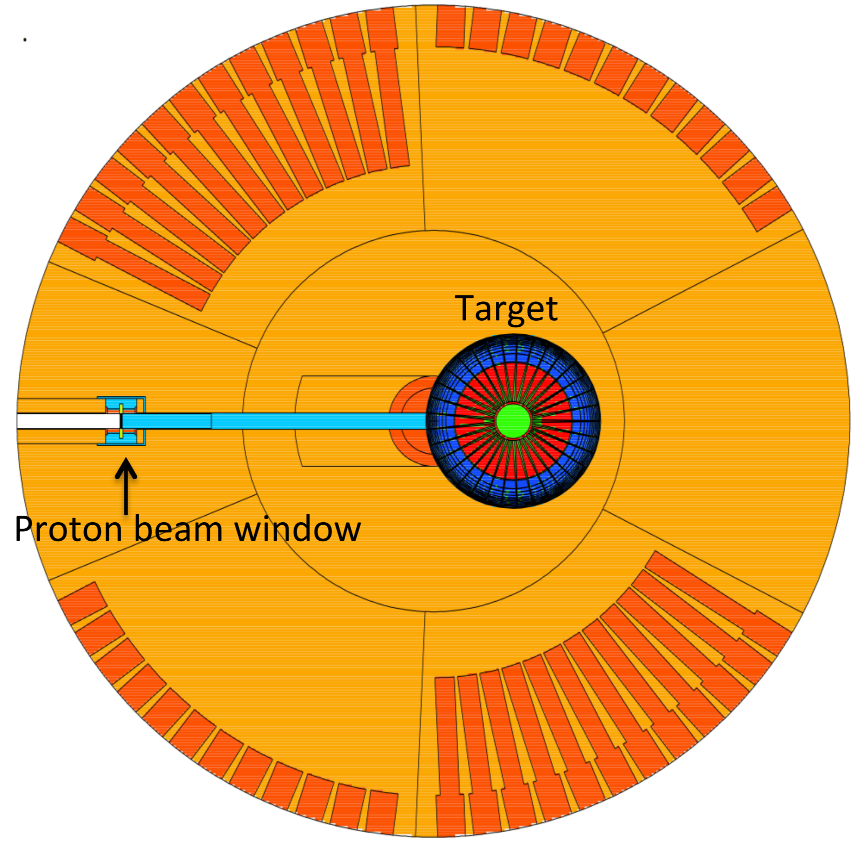


Neutronically-activated subsystems are housed in the target monolith: 7,000 tons of steel shielding

Moderators & reflectors

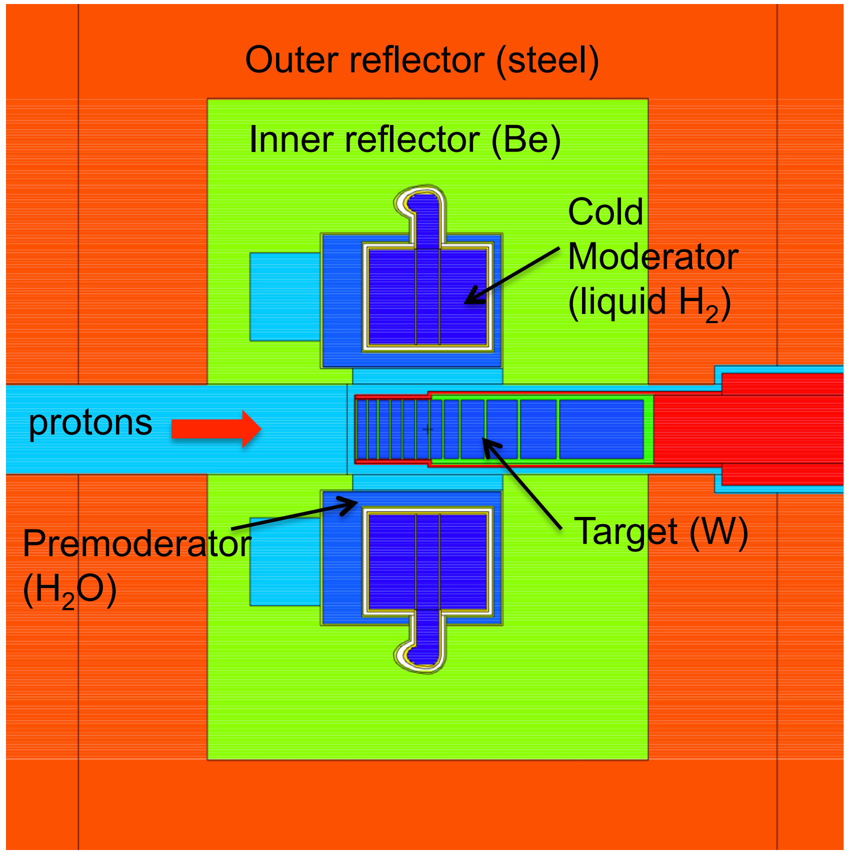
Plan view: top moderator & beam ports

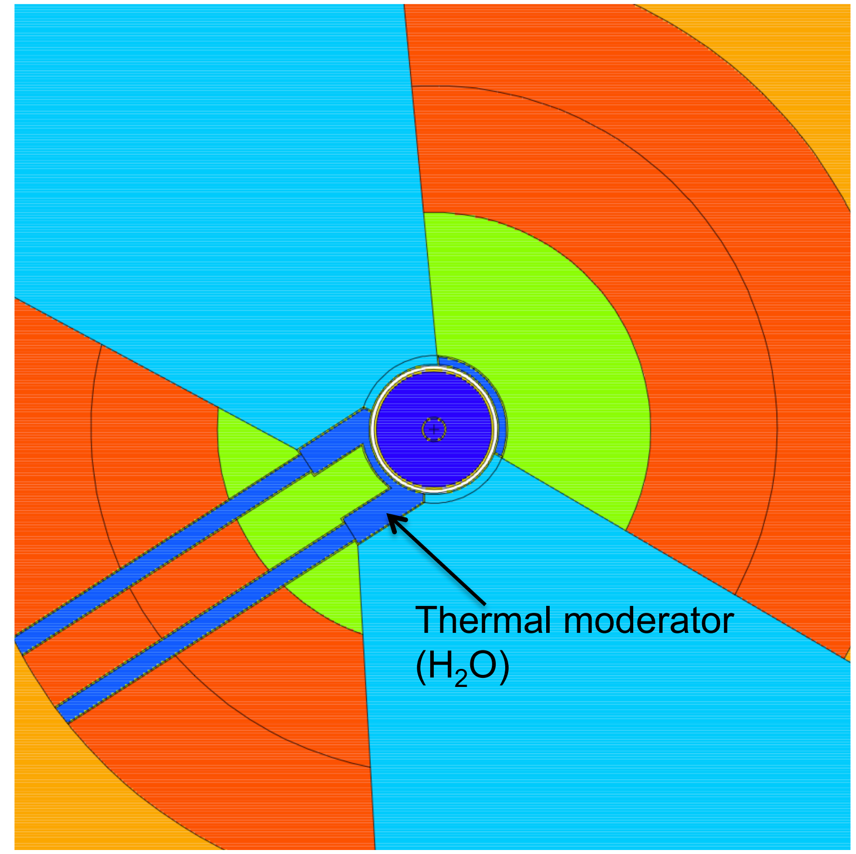




Plan view: proton beam line & target

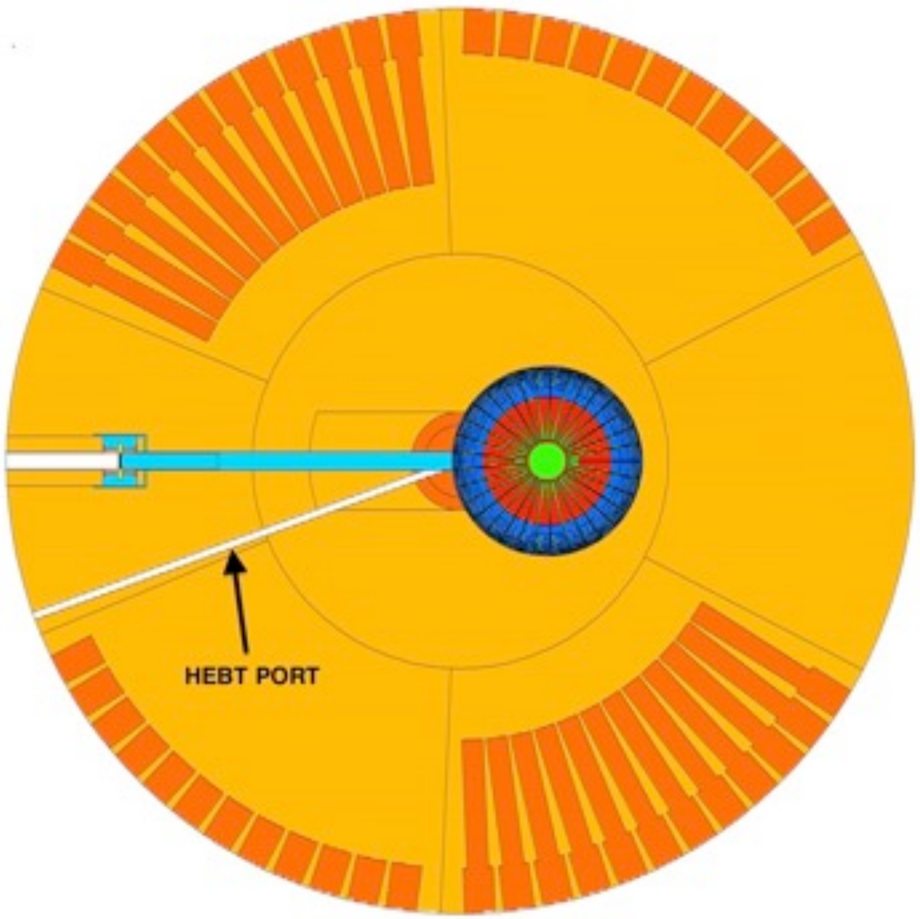
Side view: liquid H_2 moderators



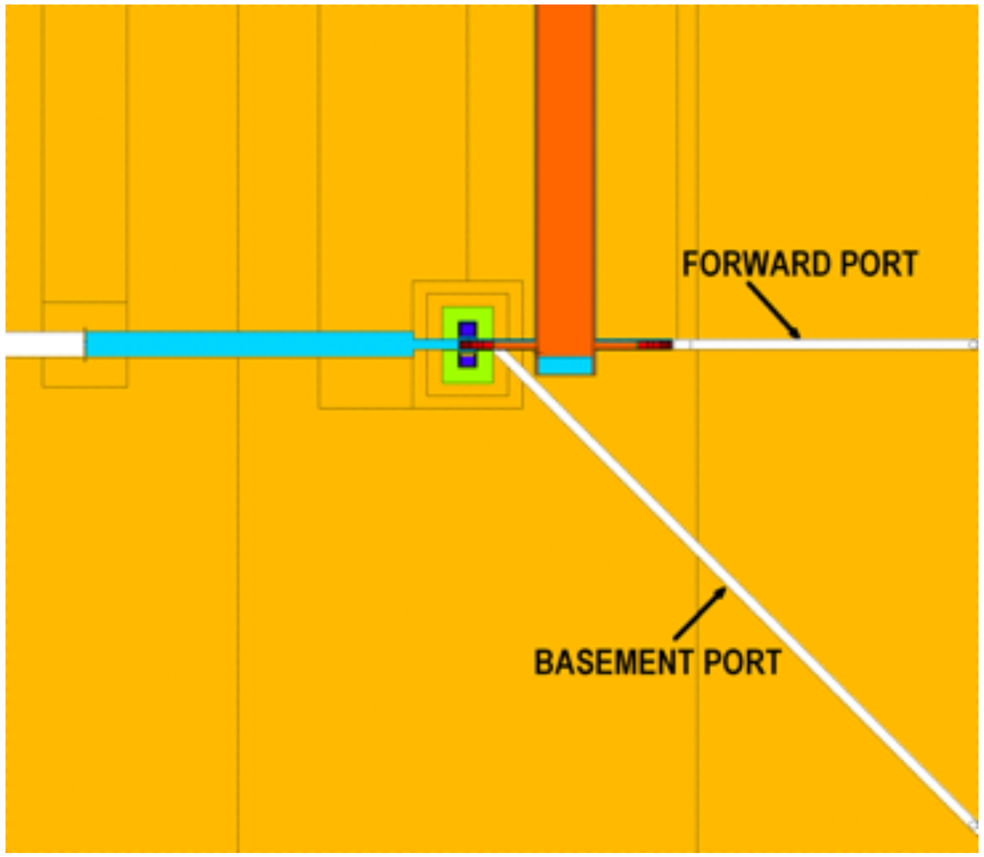


Plan view: liquid H_2 & thermal water moderators

Fast neutron ports



HEBT port



Forward & basement ports

Fast neutron spectra (possibly mixed with proton spectra) can be extracted to irradiate samples and components.

Primary goal: irradiate components or materials in target station R&D.

Potential goals: irradiation of fusion materials; tests of microchips; ...

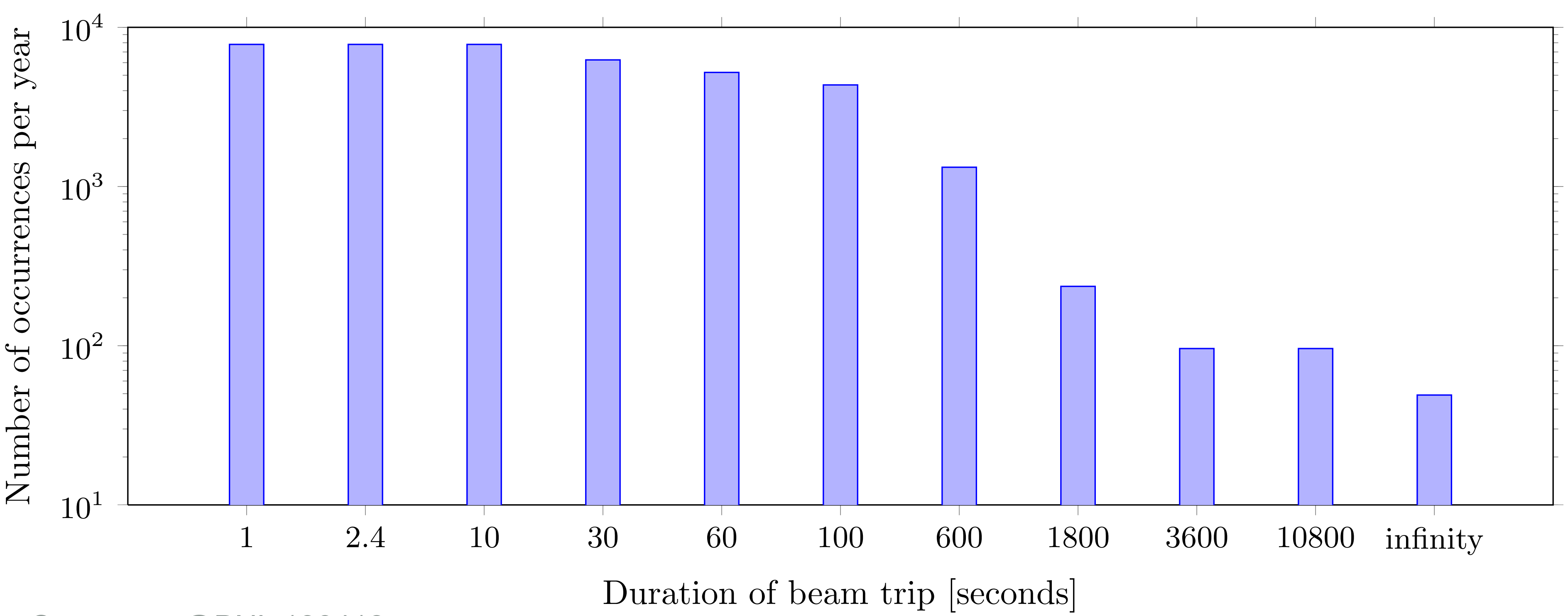
95% availability ?

ESS mode	Beam power [MW]	Occurence rate [per year]	Duration [days]	Beam trip rate [× reference]	Down time [days/year]
Maintenance	0	1	64	–	64
		1	10	–	10
		2	3	–	6
(sub-total)		4			80
Studies	0.05	33	1	10	33
		5	3	10	15
(sub-total)		38			48
Restart	< 5.0	21	1/3	2	7
		5	1	2	5
(sub-total)		26			12
Production	5.0	17	12	1	204
		3	7	1	21
(sub-total)		20			225

Availability & reliability models (eg used in target design) assume different proton beam trip rates in different operational modes

….

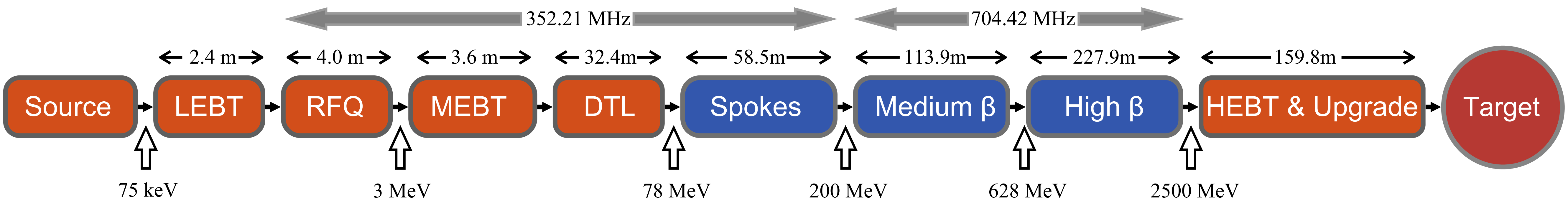
proton beam trips — reference design values for TS



…. based on a "reference rate" for beam trips in nominal power operation in the production mode.

Accelerator

FDSL_2012_10_02



The proton ion source is a compact electron cyclotron resonance source (ECR) similar to those currently in operation (Catania, Saclay).

Low energy beam transport leads to a radio-frequency quadrupole similar to an RFQ now commissioning at Saclay.

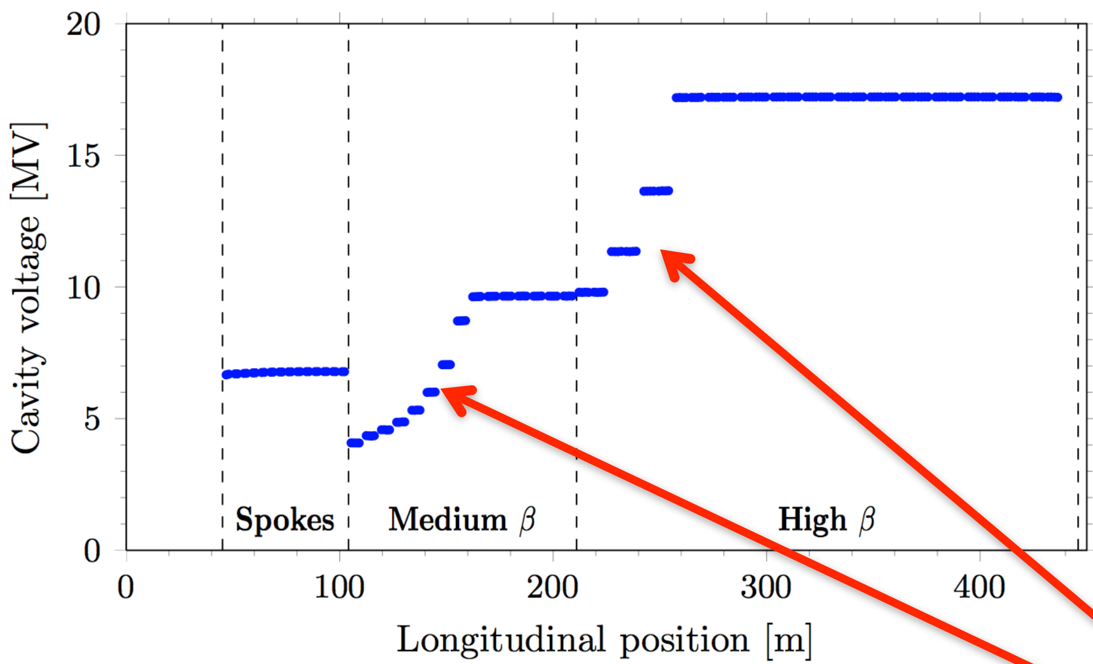
Then through a drift tube linac and a medium energy beam transport.

Most of the 2.5 GeV & 5 MW acceleration is in the superconducting linac of the linac, using both spoke and elliptical cavities.

Superconductivity is achieved at a nominal temperature of 2 K, inside individual helium vessels, or cryomodules.

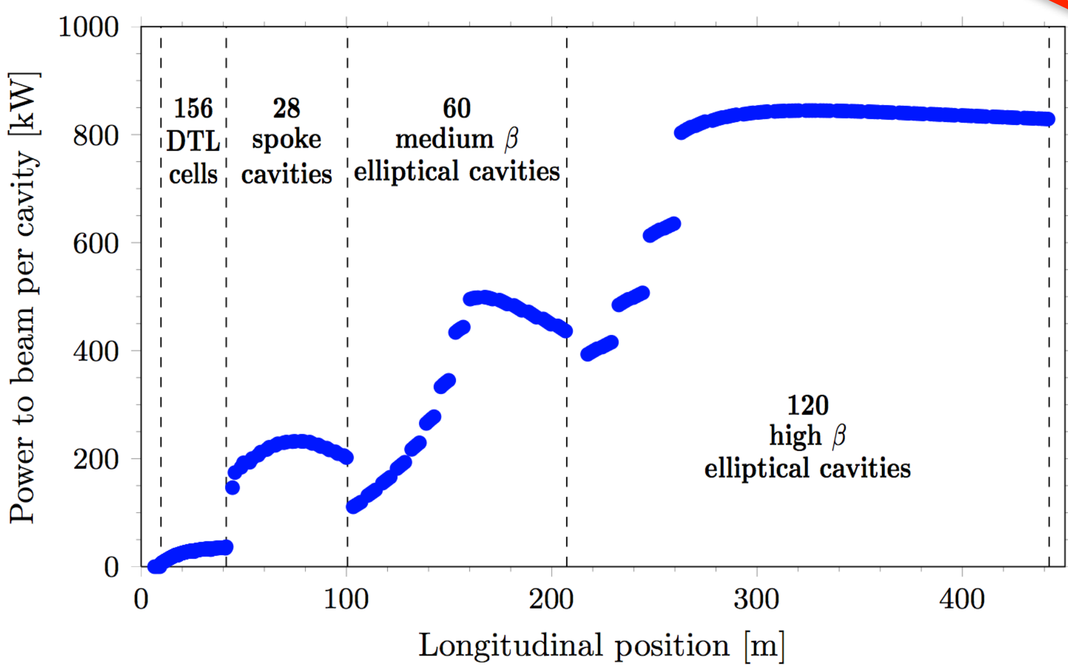
Finally, the high energy beam transport takes beam to the target. The HEBT contains space for potential energy abd/or power upgrades.

Longitudinal proton optics

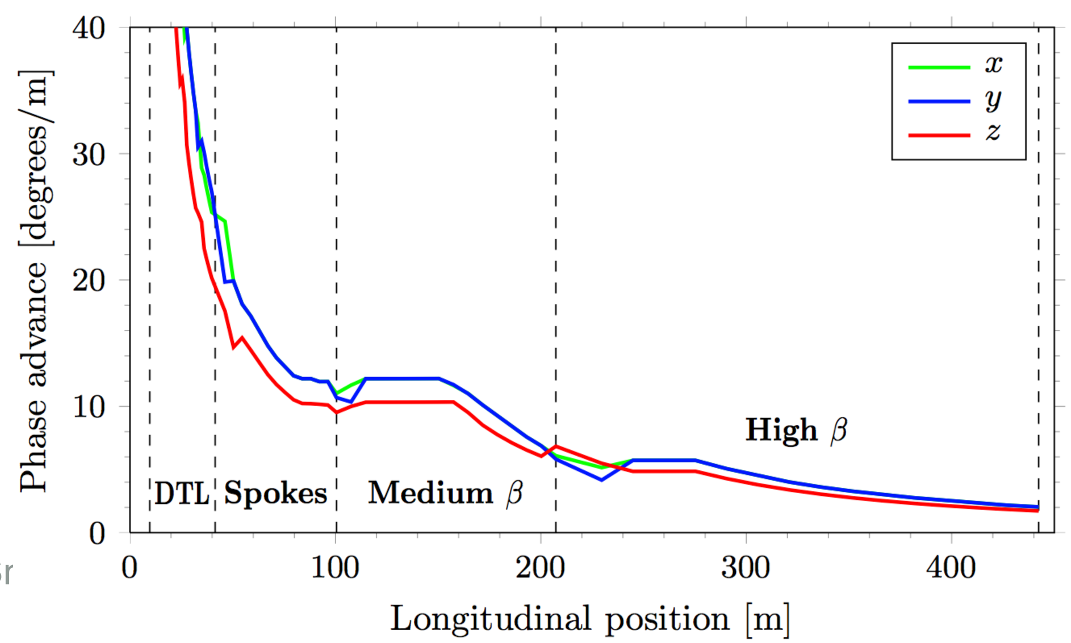


Cavity voltage vs distance along the linac, from the DTL to the end of the high-β section

What is the cost-benefit analysis for optical perfection? Optimisation?

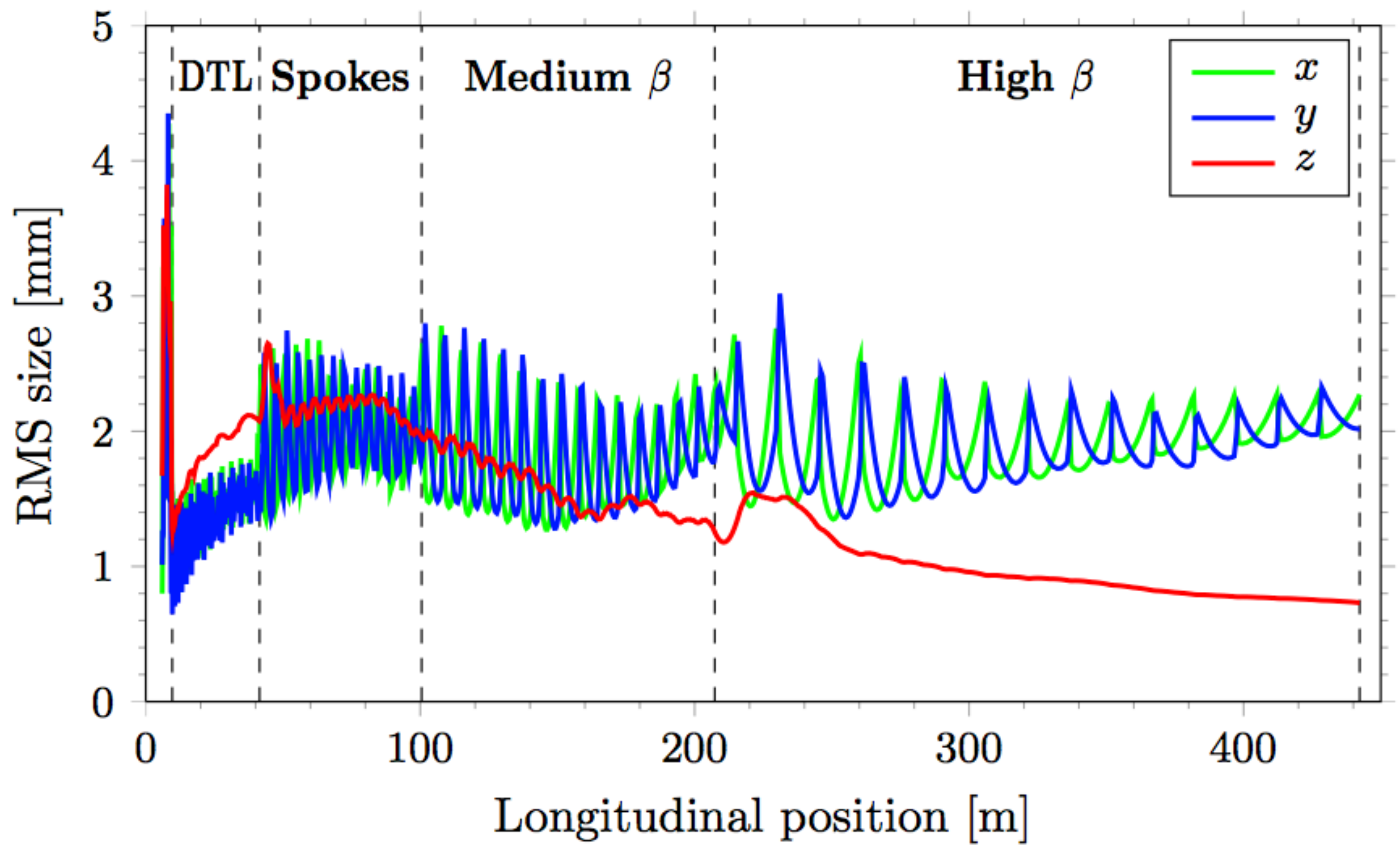


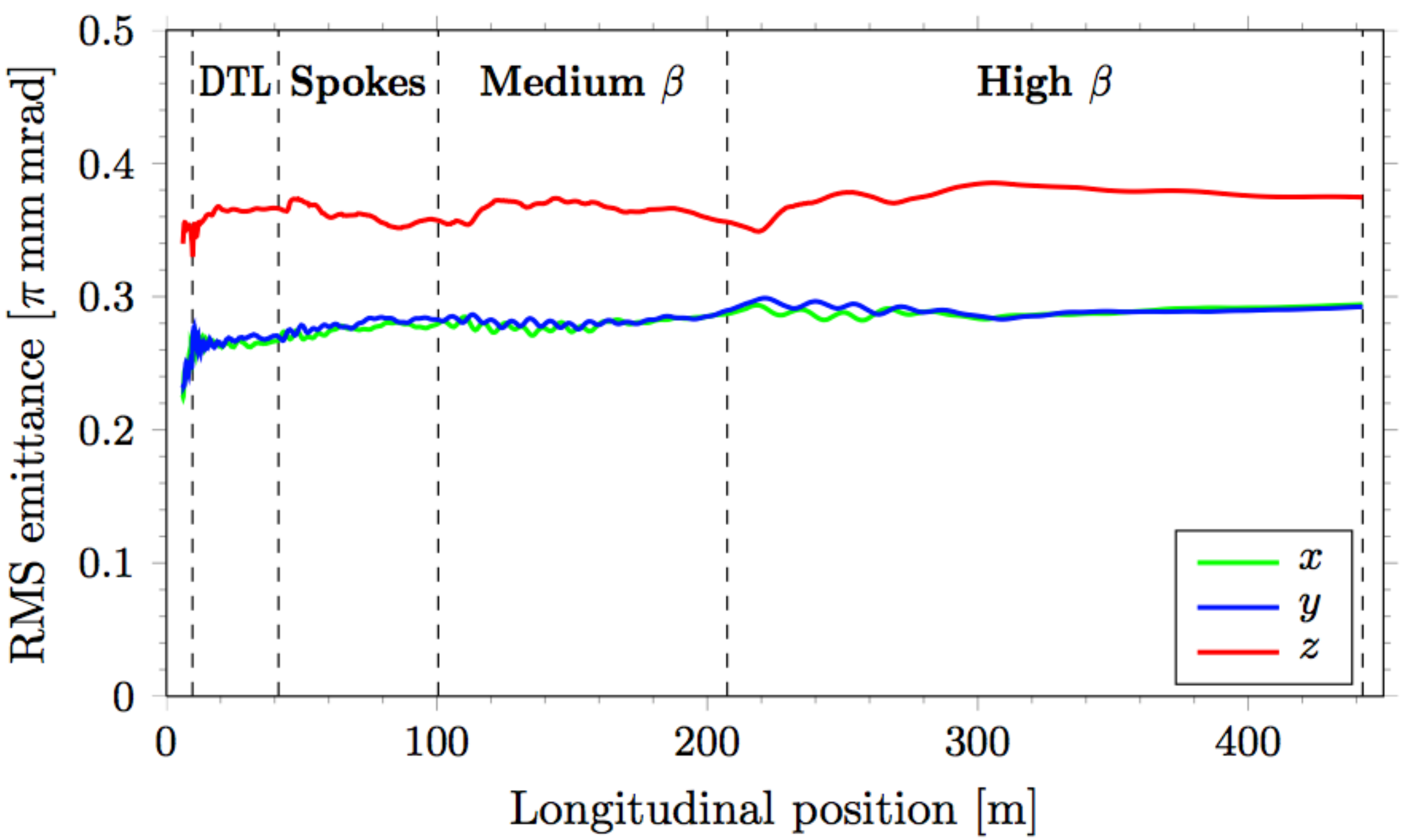
Power delivered to a 50 mA beam in each DTL cell & superconducting cavity



The rate of phase advance (like 1/β) from DTL to the end.

Beam sizes & emittances



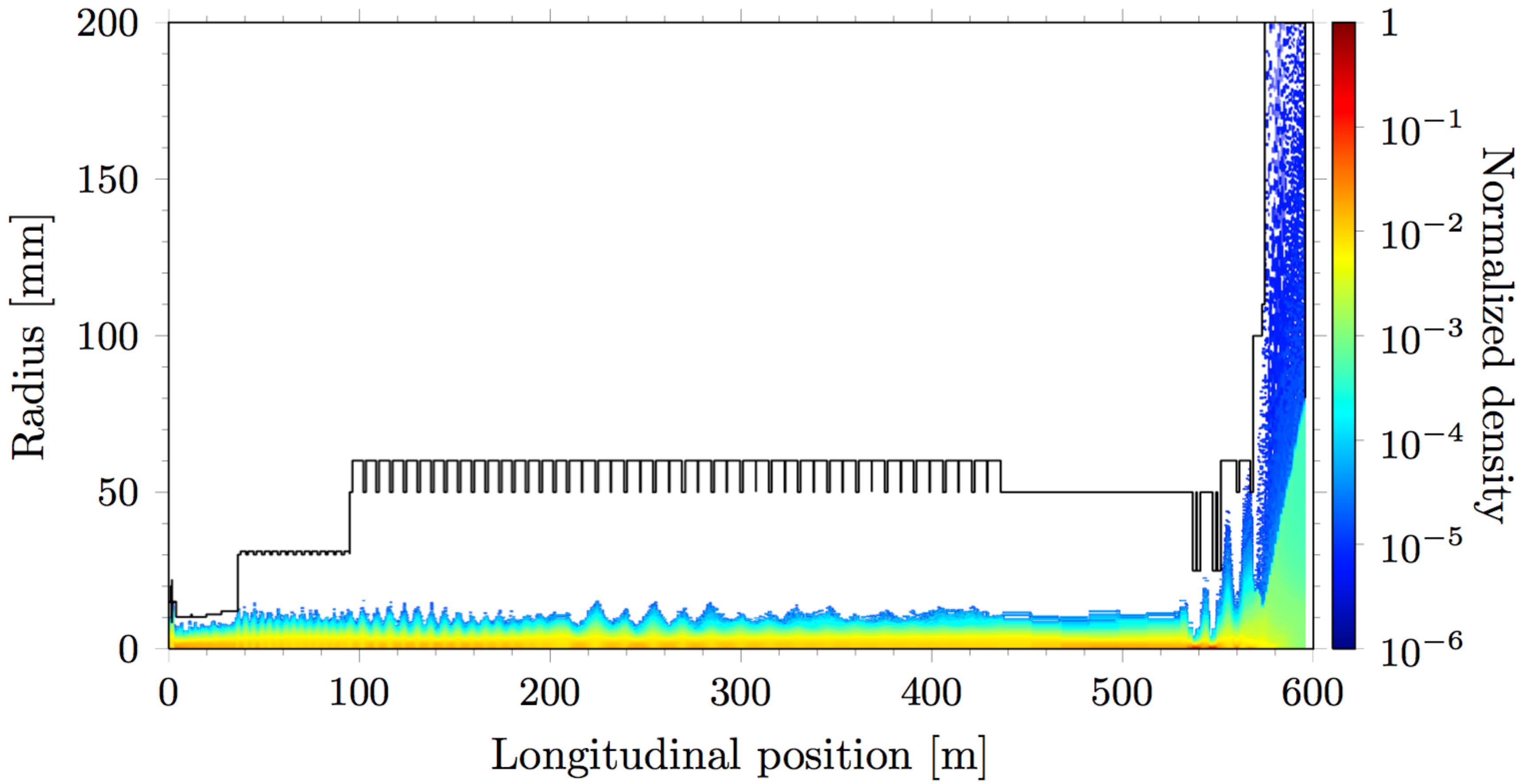


Superconducting cavities have a large aperture, compared to the RMS (transverse) beam sizes

Very little emittance growth seen so far, although more studies need to be done.

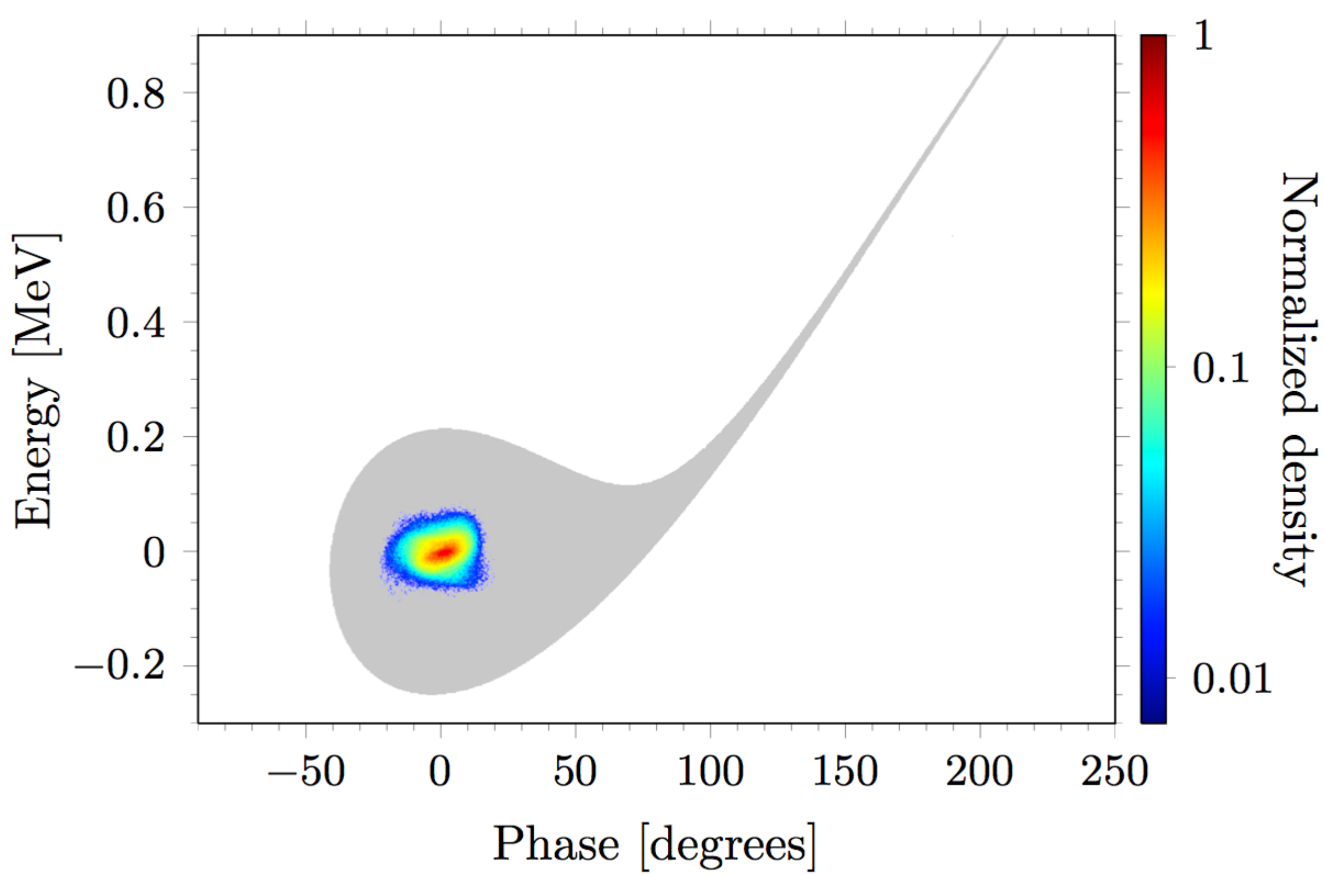
But the issue is halo growth: keep beam losses below 1 W/m, out of a 5 MW beam !

Halo & acceptance



Particle density vs distance & radius along the linac, from the MEBT to the target.

Beam-spreading makes a 160 mm x 60 mm beam profile on the target.

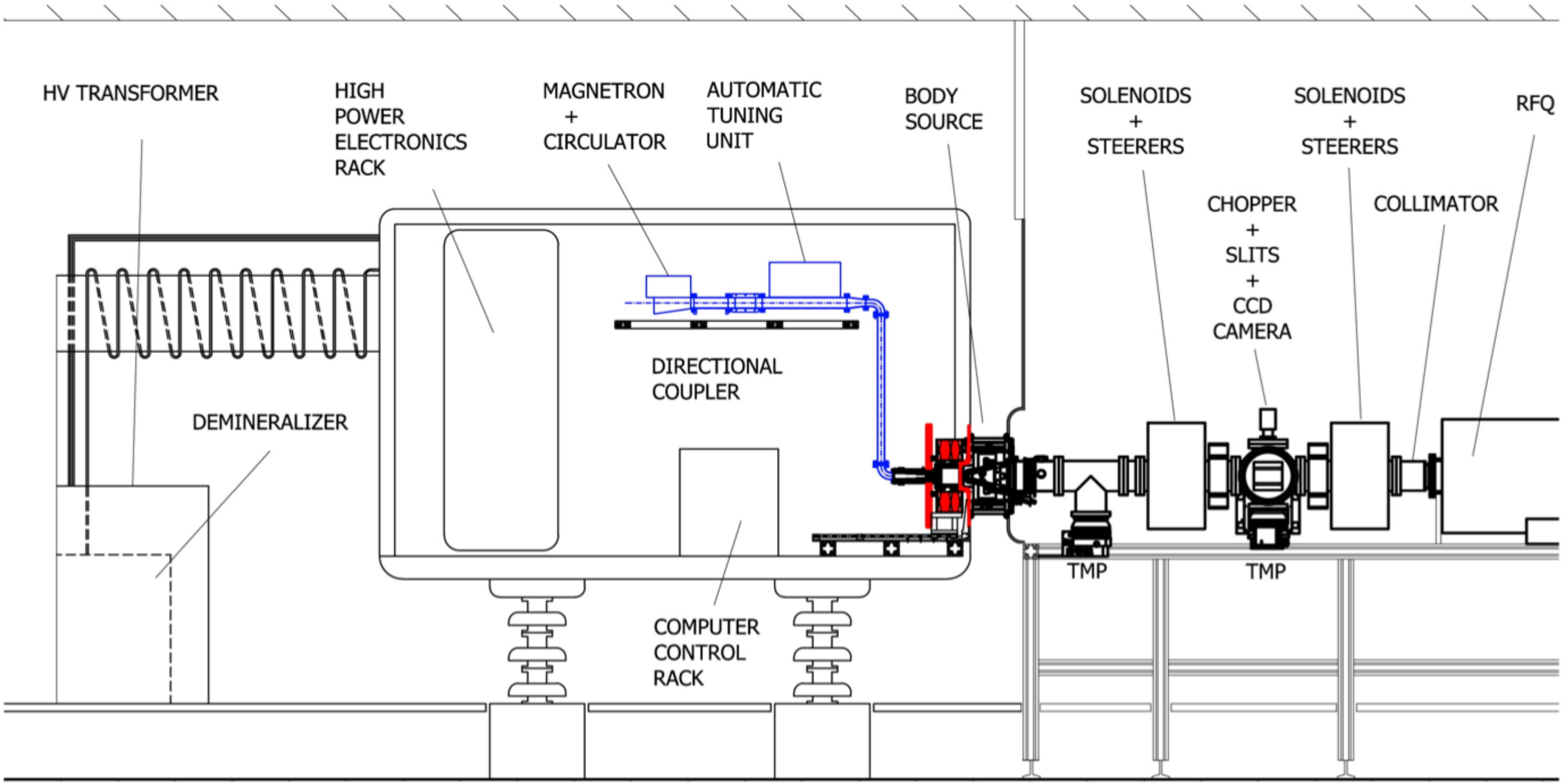


Longitudinal acceptance (referred to the DTL entrance).

Protons entering the DTL inside the grey area reach the HEBT.

“Actual” beam out of the MEBT is the central coloured distribution.

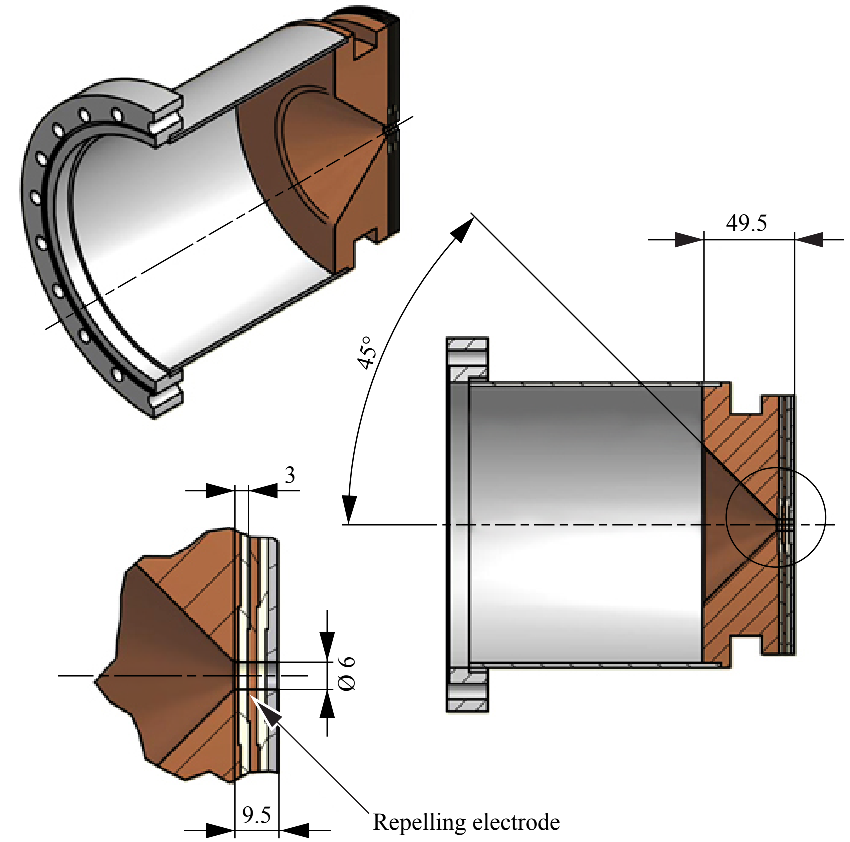
Ion source & LEBT

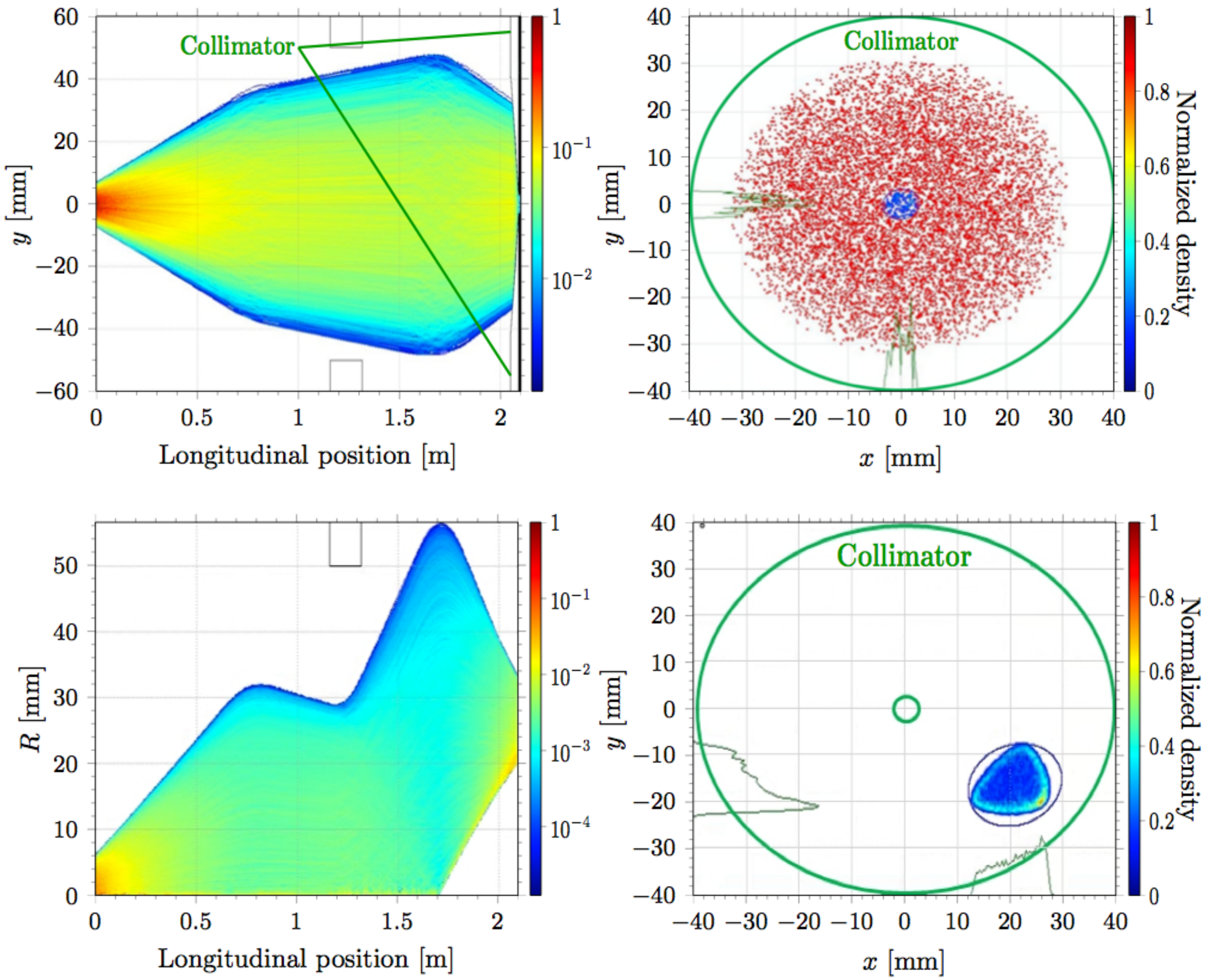


Beam is extracted from the ion source through the low energy beam transport chopper that incorporates beam emittance measurement slits, followed by a collimator just before entrance to the RFQ.

LEBT collimation

RFQ collimator at the end of the LEBT, with integrated repelling electrode



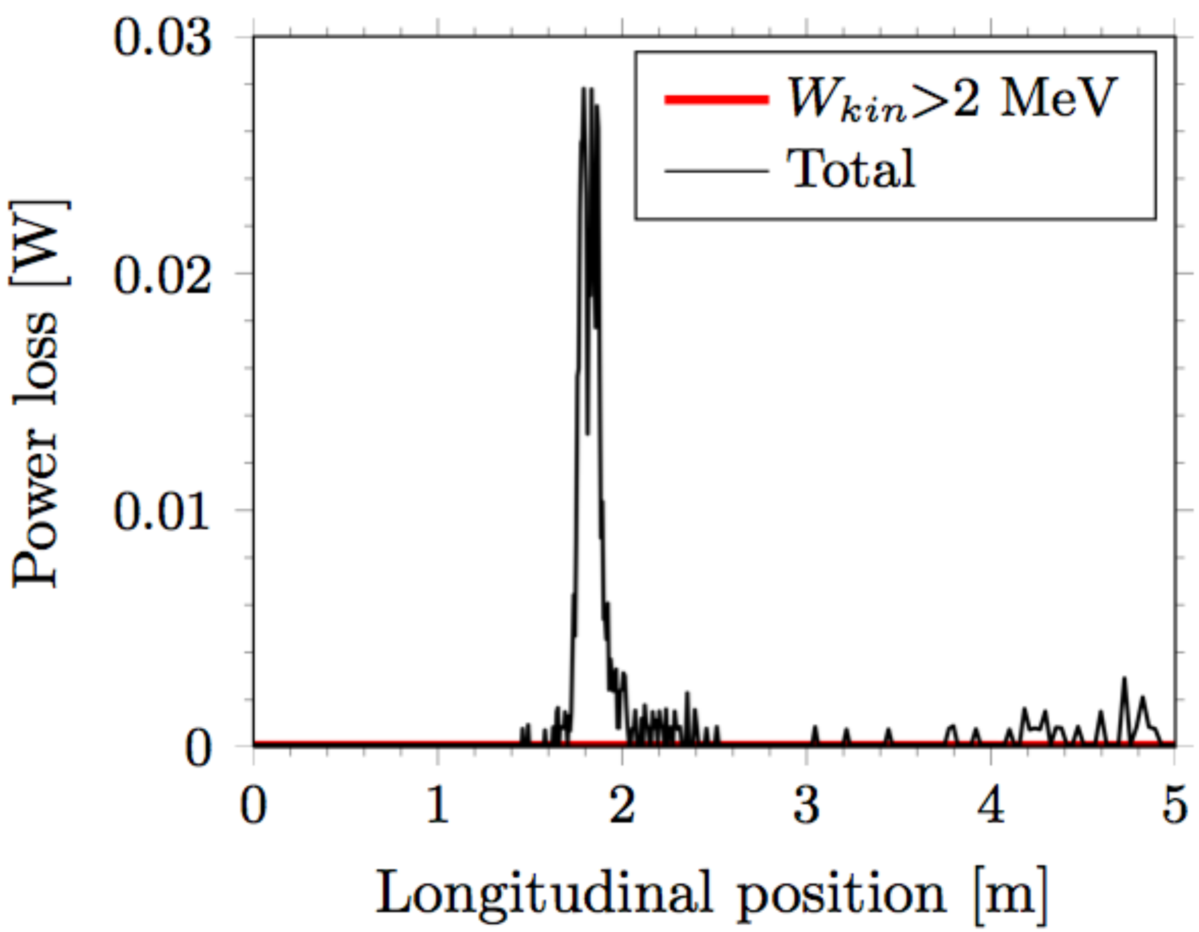


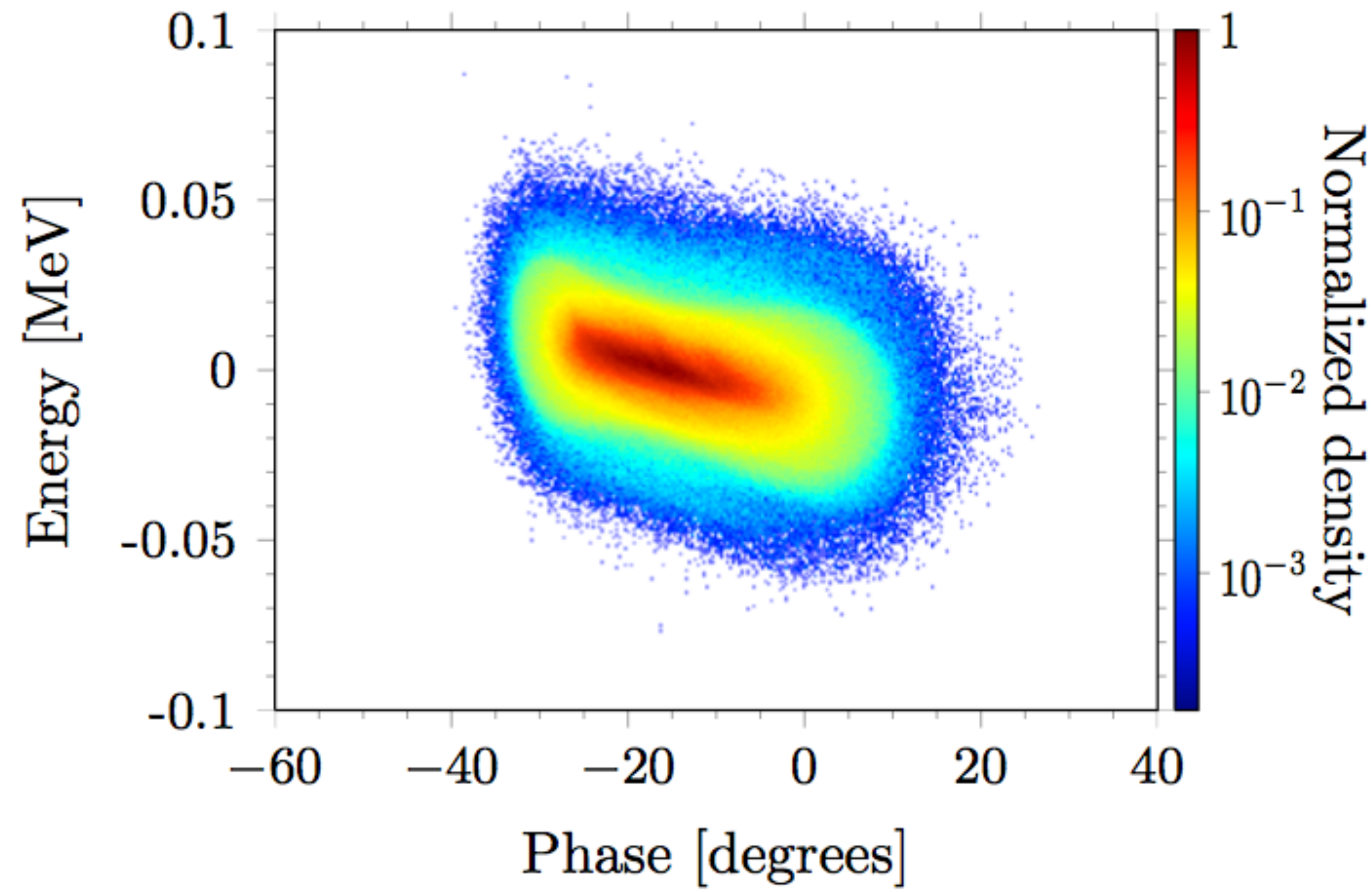
Secondary (H_2^+) beam trajectories, and distribution on the collimator.

When “ON”, the chopper deflects the proton beam out of collimator centre line.

Solenoids rotate deflected beam by 45 degrees.

Radio frequency quadrupole





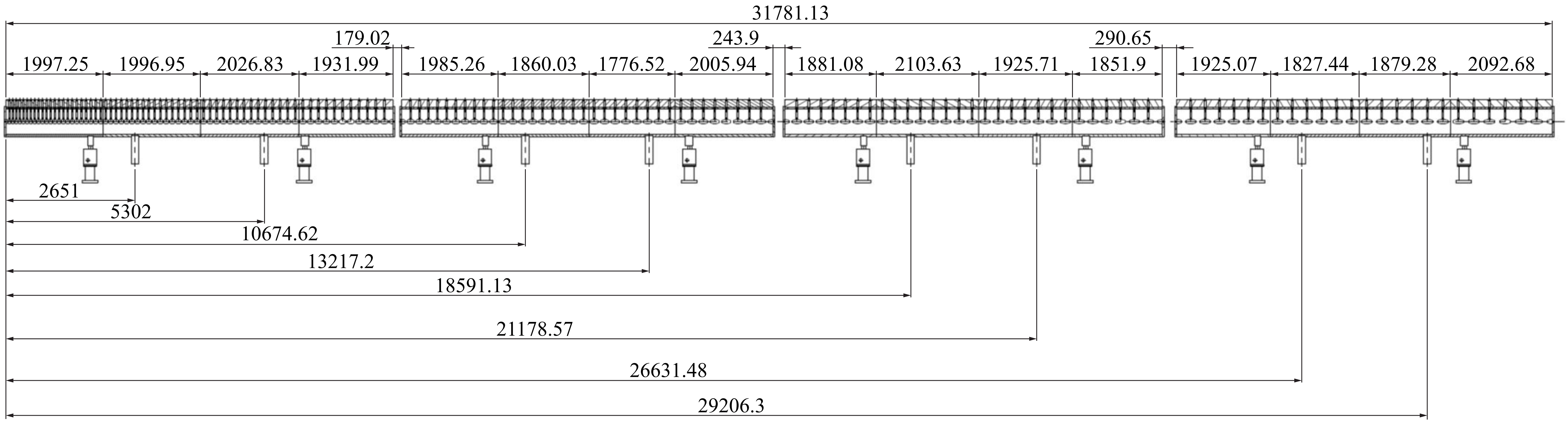
Beam losses along the RFQ.

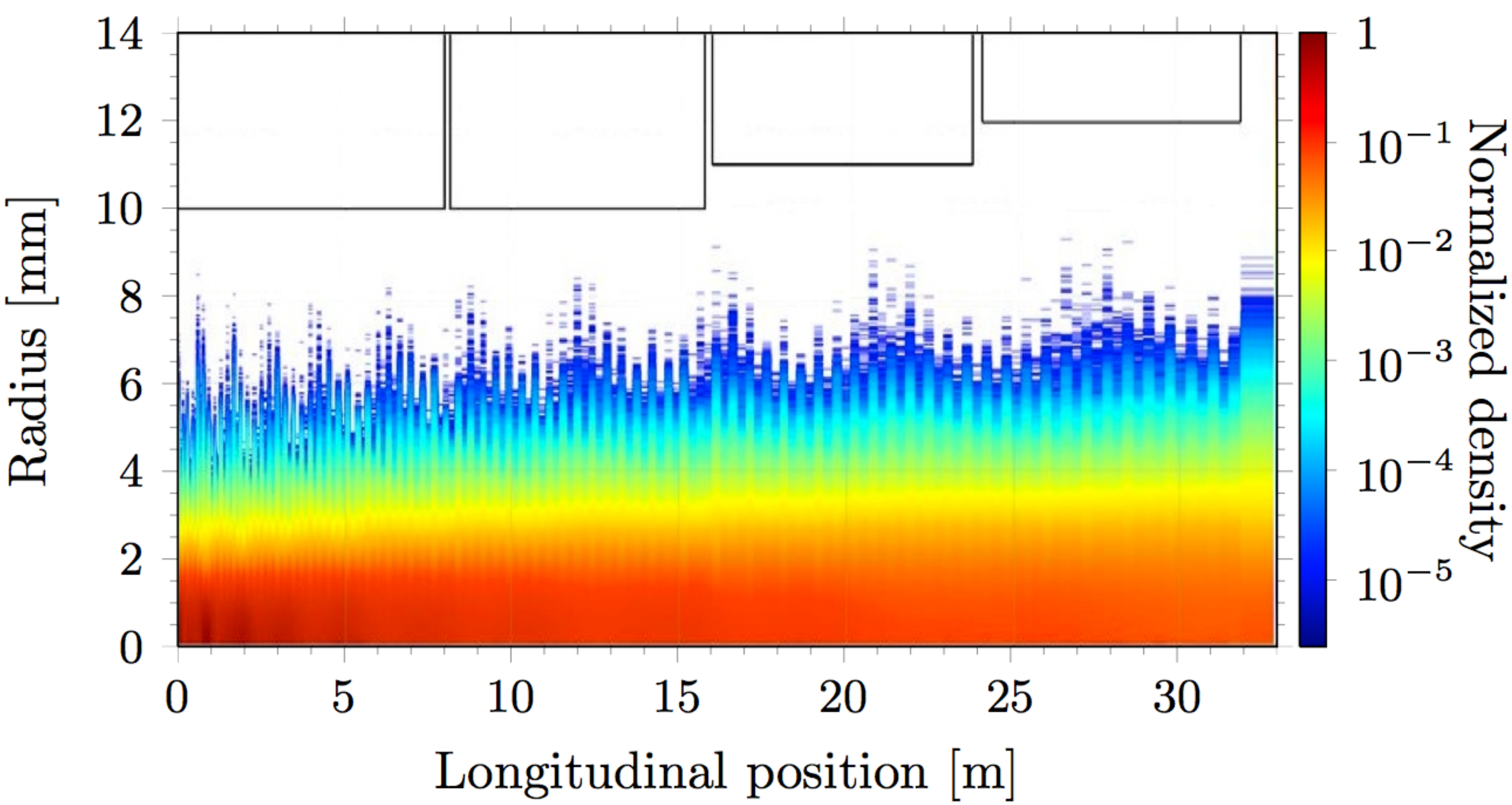
The usual 1 W/m loss limit does not apply at these low energies (eg 2 MeV).

Longitudinal phase space distribution at the RFQ output.

For an 50 mA beam current & an emittance of 0.2 π mm mrad.

Drift tube linac





Overall layout & dimensions of the four DTL tanks.

Evolution of the beam distribution along the DTL.

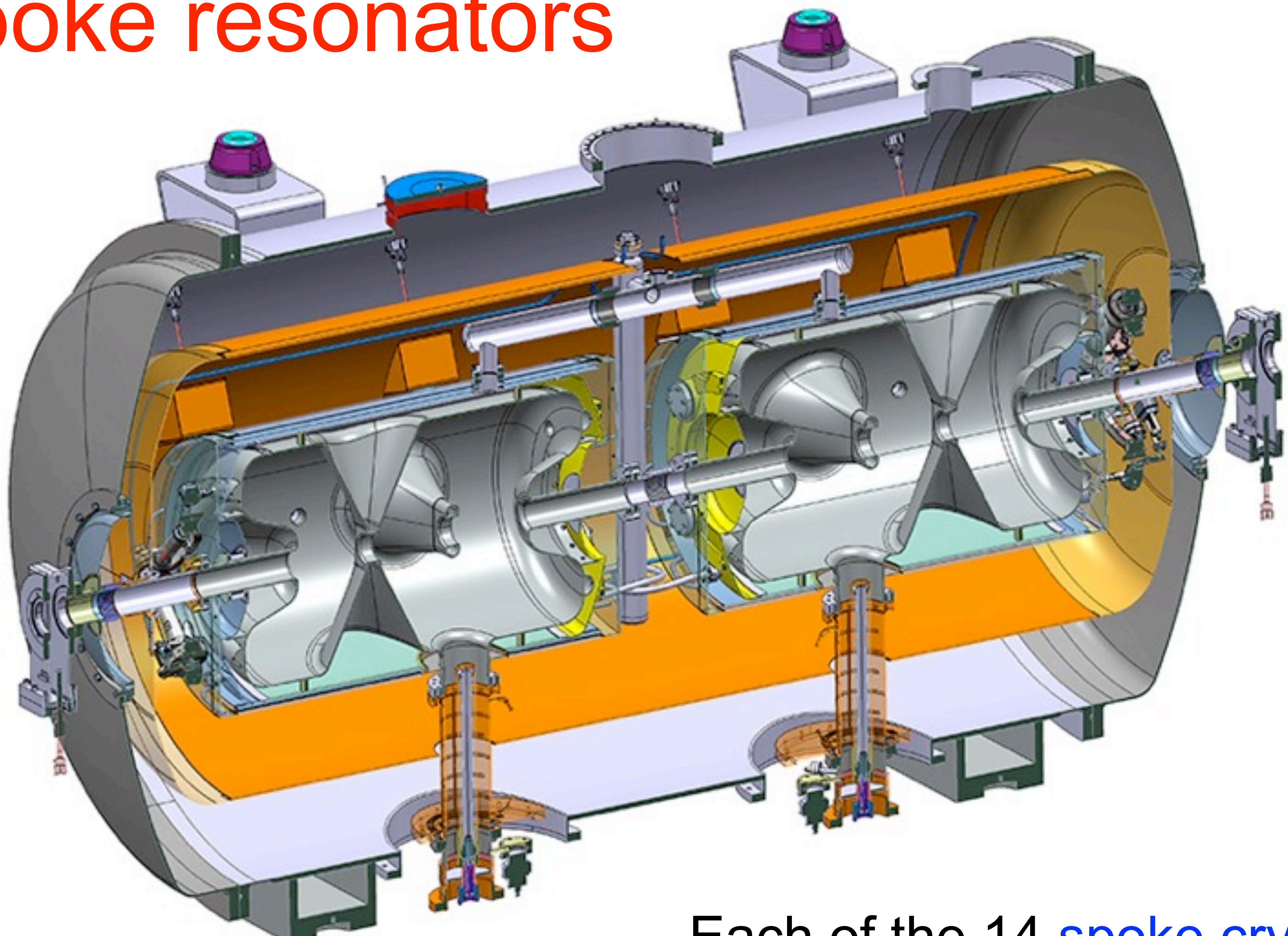
SRF cavities & cryomodules

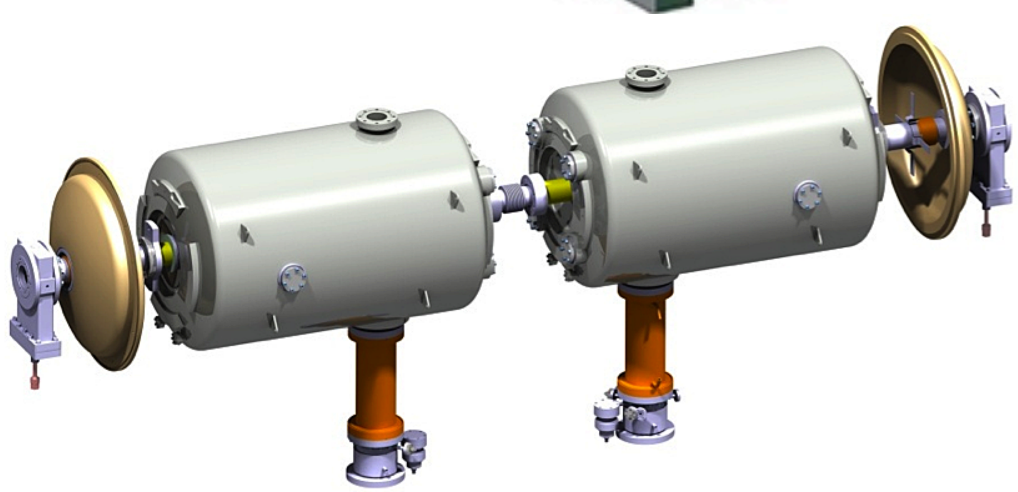
	Length [m]	Input energy [MeV]	Frequency [MHz]	Geometric β	No. of tanks or modules	No. of cells or cavities	Temp. [K]
LEBT	2.4	0.075					
RFQ	4.0	0.075	352.2		4		300
MEBT	3.6	3					
DTL	32.4	3	352.2		4	156	300
Spoke	58.5	78	352.2	0.50	14	28	≈ 2
Medium-β	113.9	200	704.4	0.67	15	60	≈ 2
High-β	227.9	628	704.4	0.92	30	120	≈ 2
HEBT	159.2	2500					

These radio frequency parameters describe the FDSL_2012_10_02 lattice in the Technical Design Report.

A modest evolution away from these parameters is to be expected ….

Spoke resonators

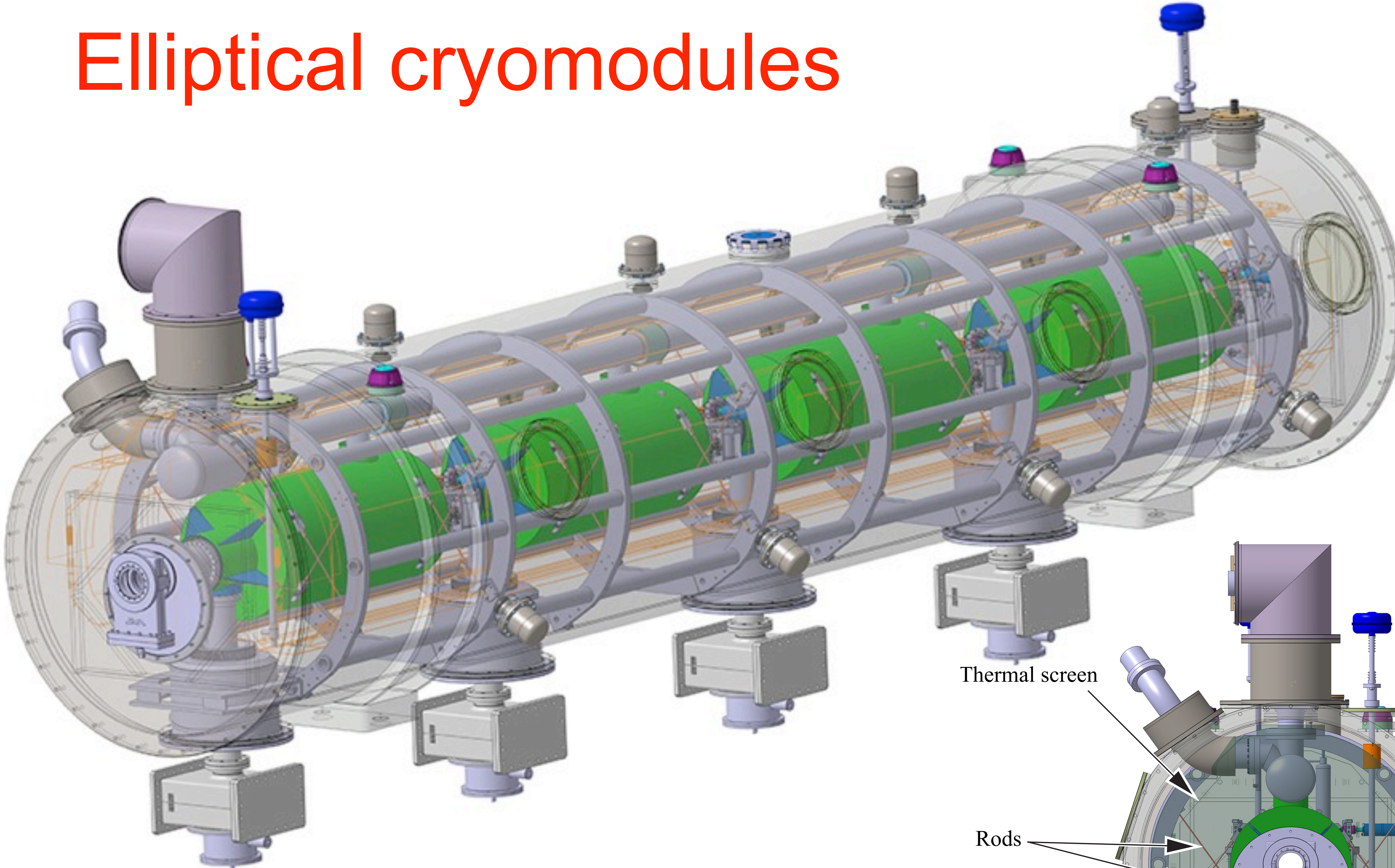


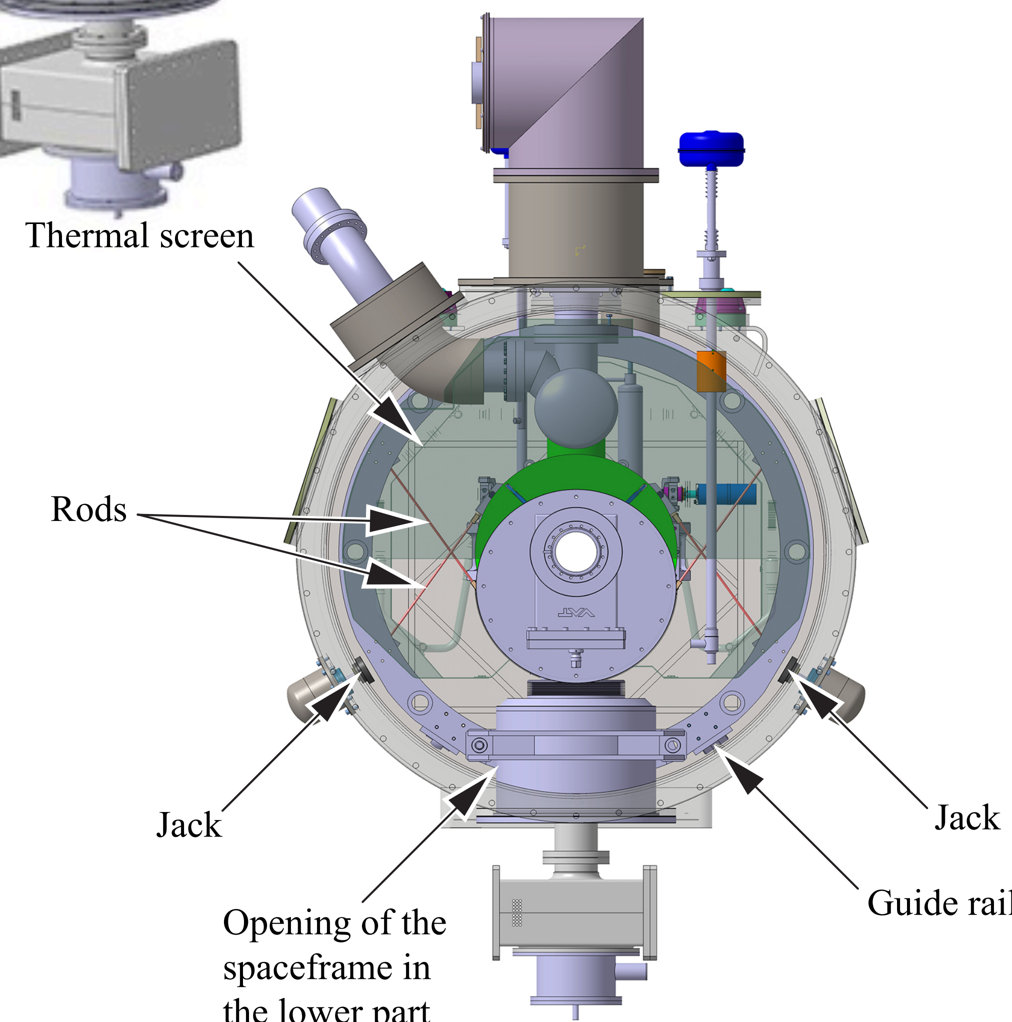


Each of the 14 spoke cryomodules contains two "double spoke" cavities (as shown here).

ESS may be the first facility to routinely operate spoke cavites.

Elliptical cryomodules



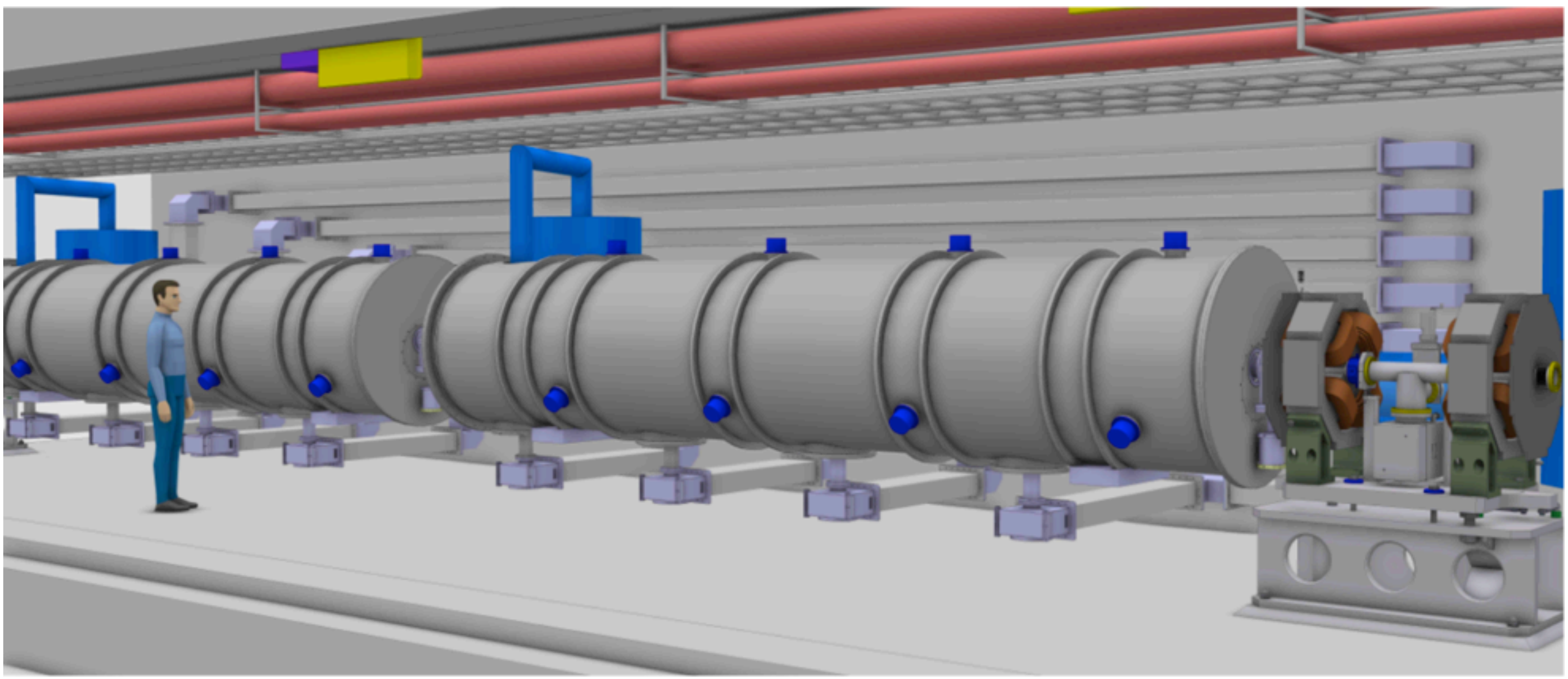


15 low-β and 30 high-β elliptical cavity cryomodules each contain four cavities

Tunnel

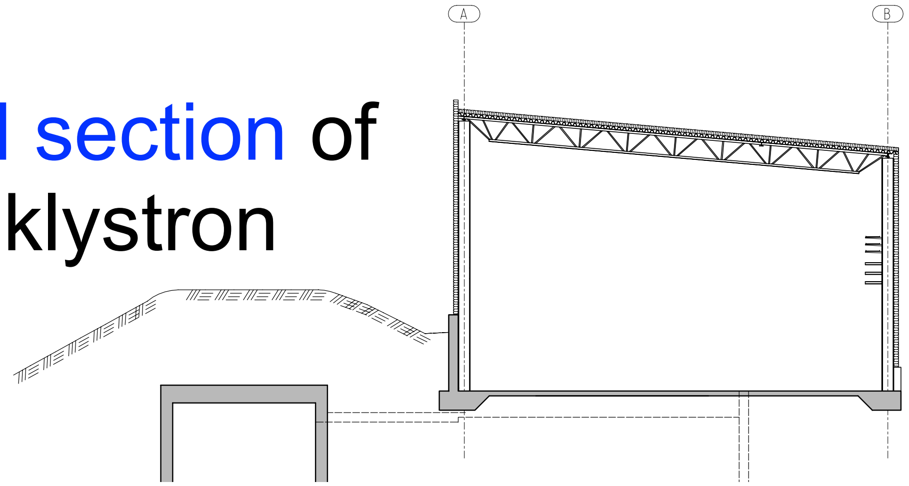
Section	Number of modules
Spoke	14
Medium-β	15
High-β	30
Total	59

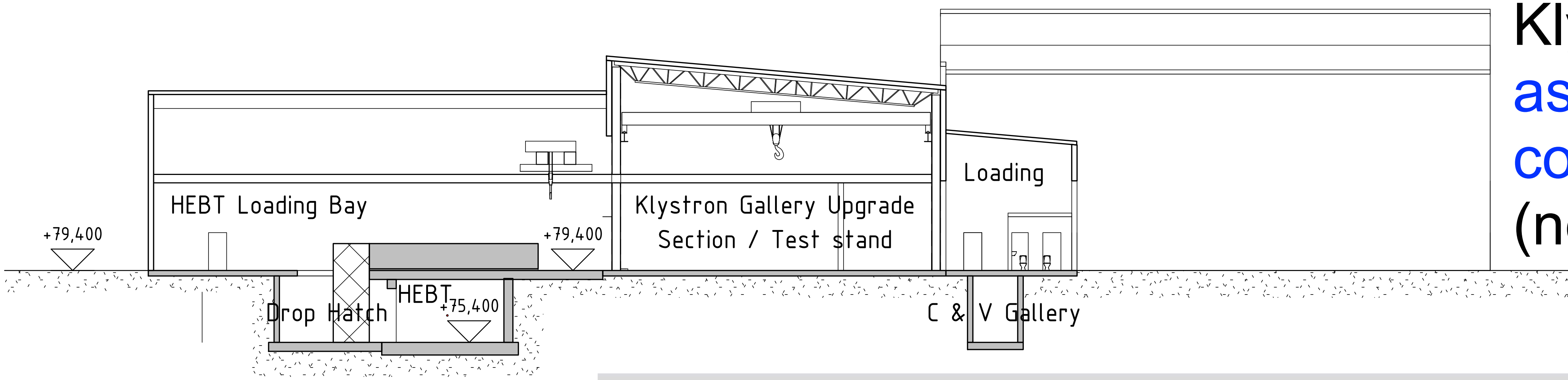
A tunnel perspective of an elliptical cavity cryomodule, shows jumper connections, valve boxes, cryogenic transfer lines, & warm quadrupoles.



Tunnel & klystron gallery

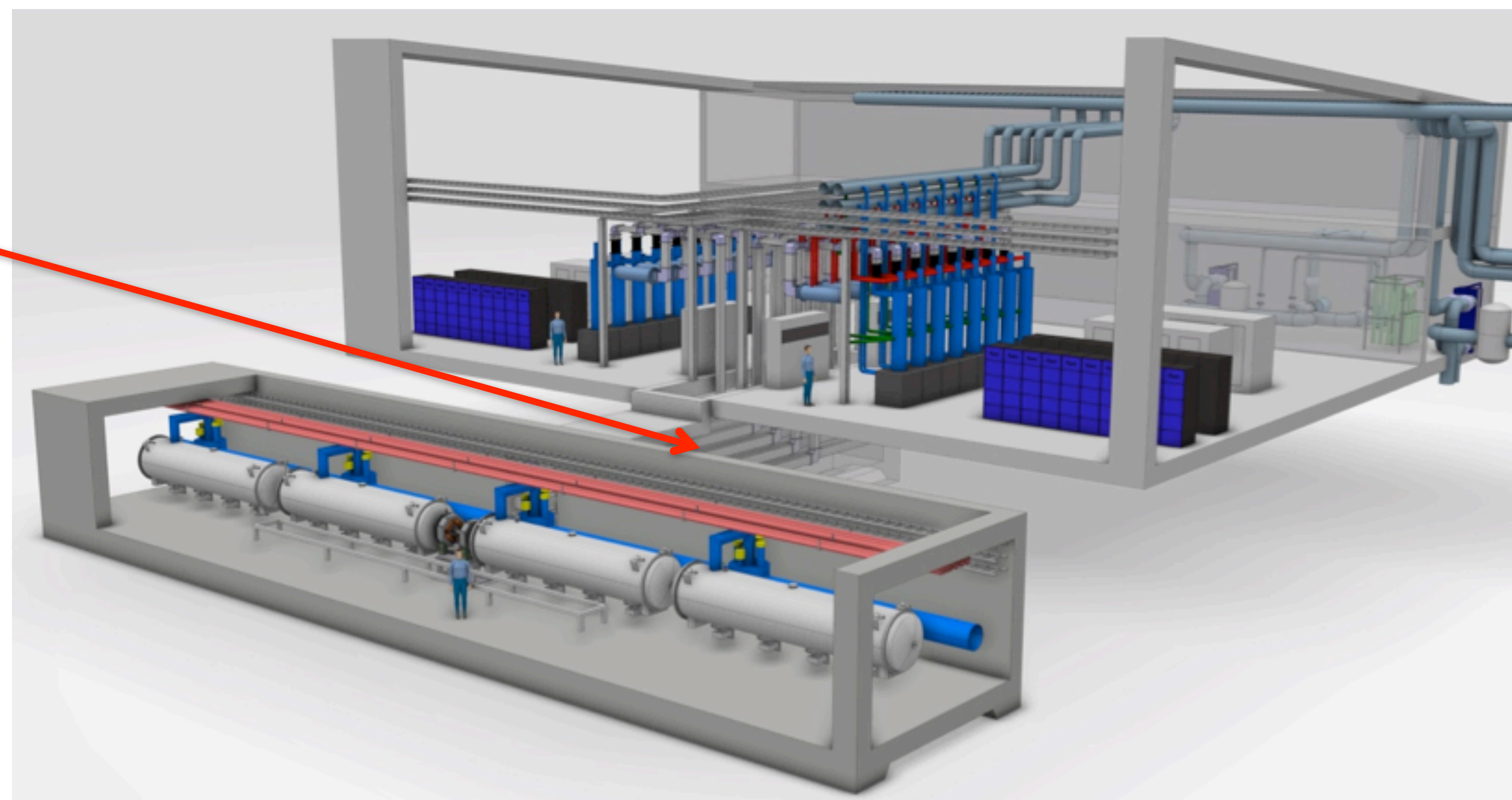
Standard section of tunnel & klystron gallery



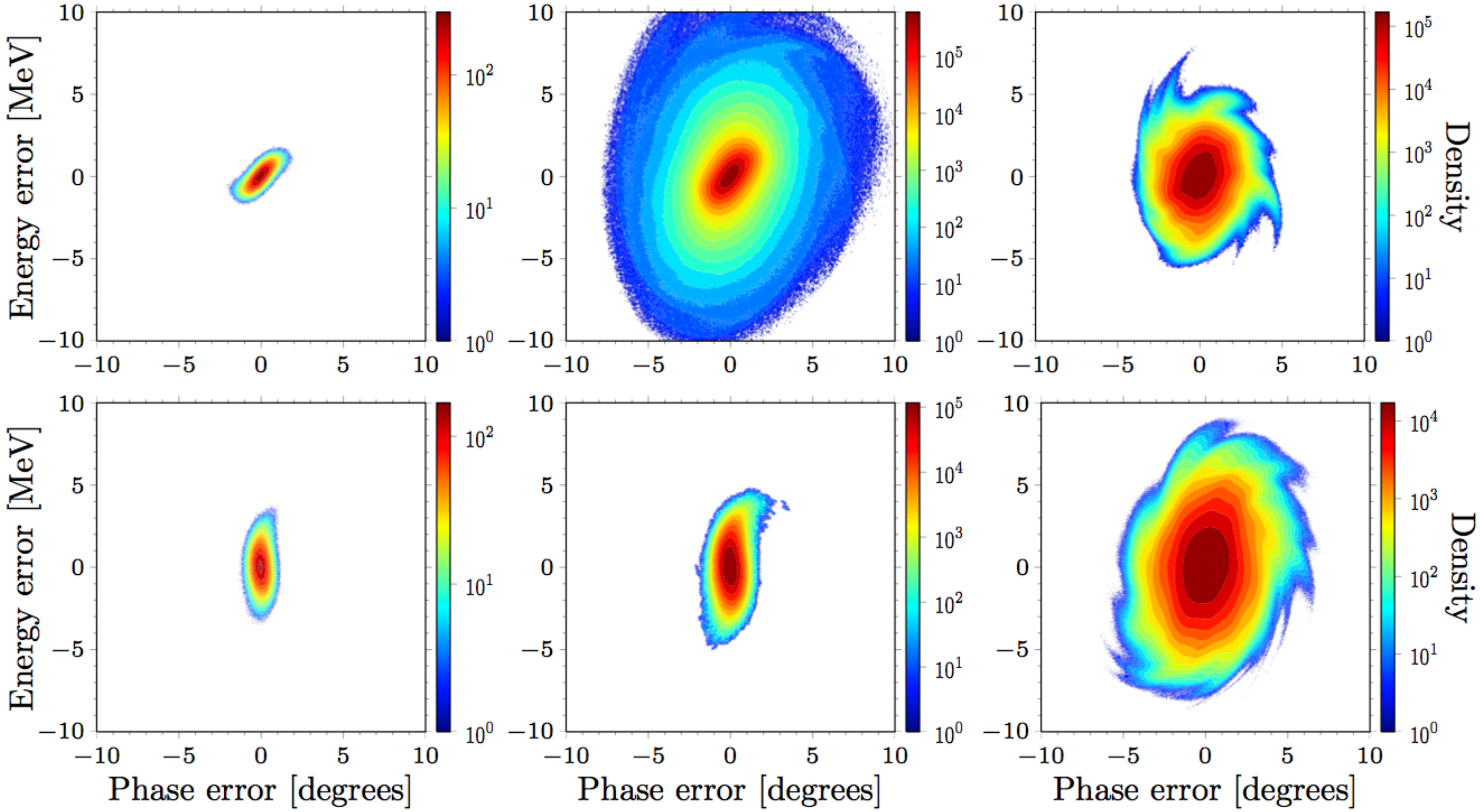


Klystron gallery assembly hall & cold box building (near target)

16 stubs (shown here in the medium-β section) connect the accelerator tunnel & the klystron gallery.



Same-order & higher-order modes



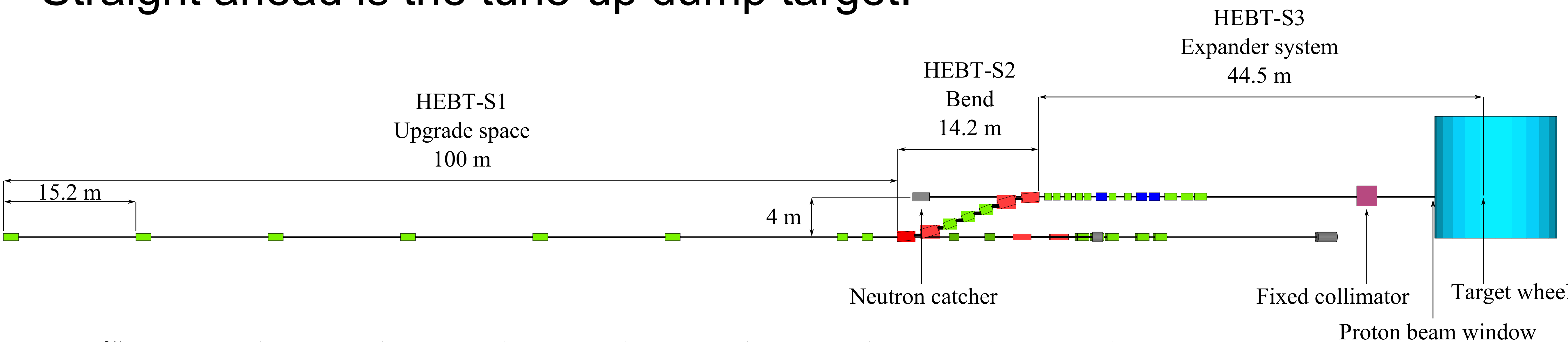
Successive bunches of the 1,007,000 bunches in a macro-pulse are deflected thanks to "same-order" and "higher" cavity modes.

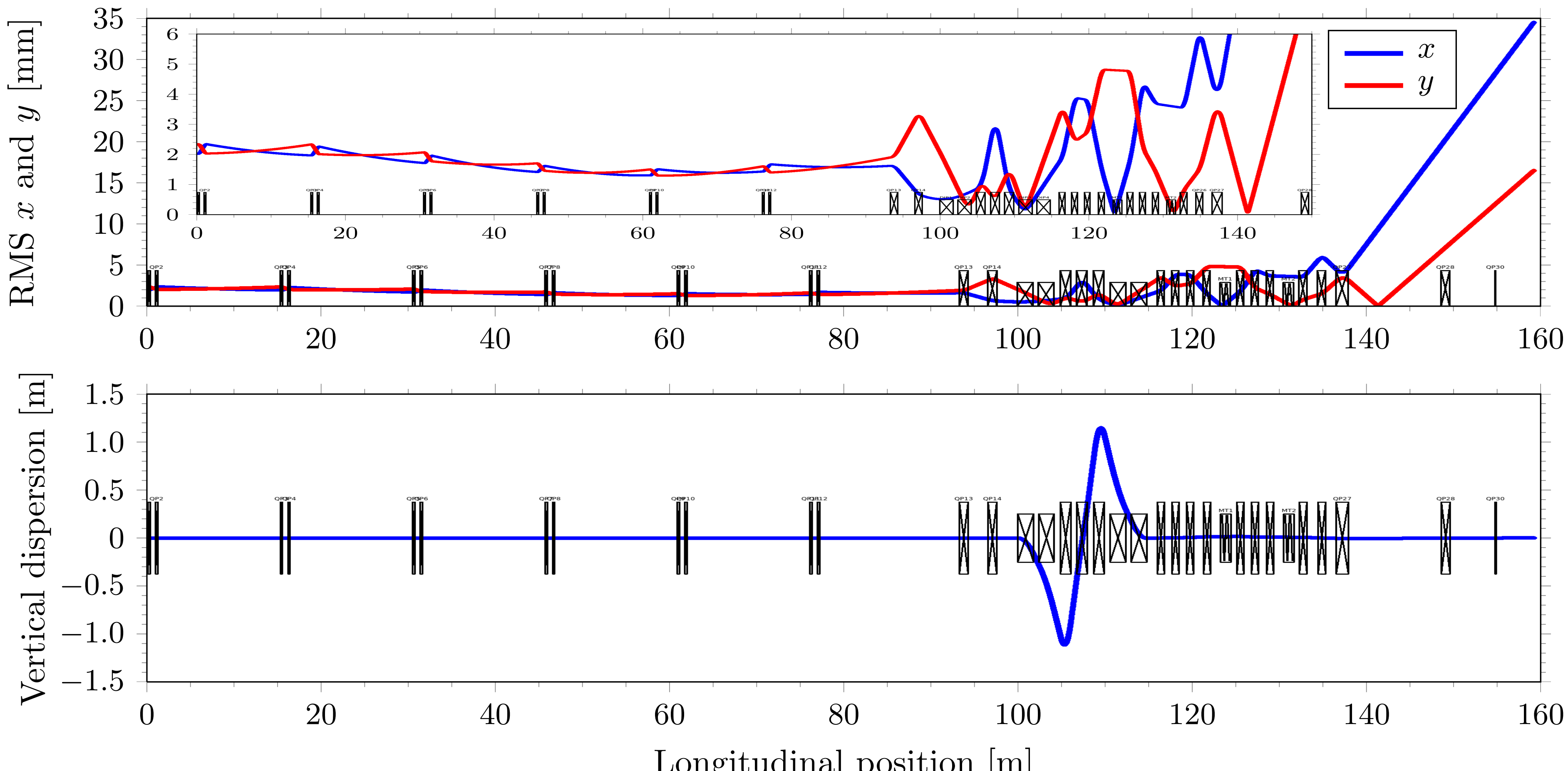
These phase space distributions are averaged over all bunches.

Top: an early lattice. Bottom: FDSL_2012_10_02 lattice. Left: no modes. Middle: with passband modes. Right: with RF errors.

High energy beam transport

Quadrupoles in green, dipoles in red, with the target monolith at far right. Straight ahead is the tune-up dump target.

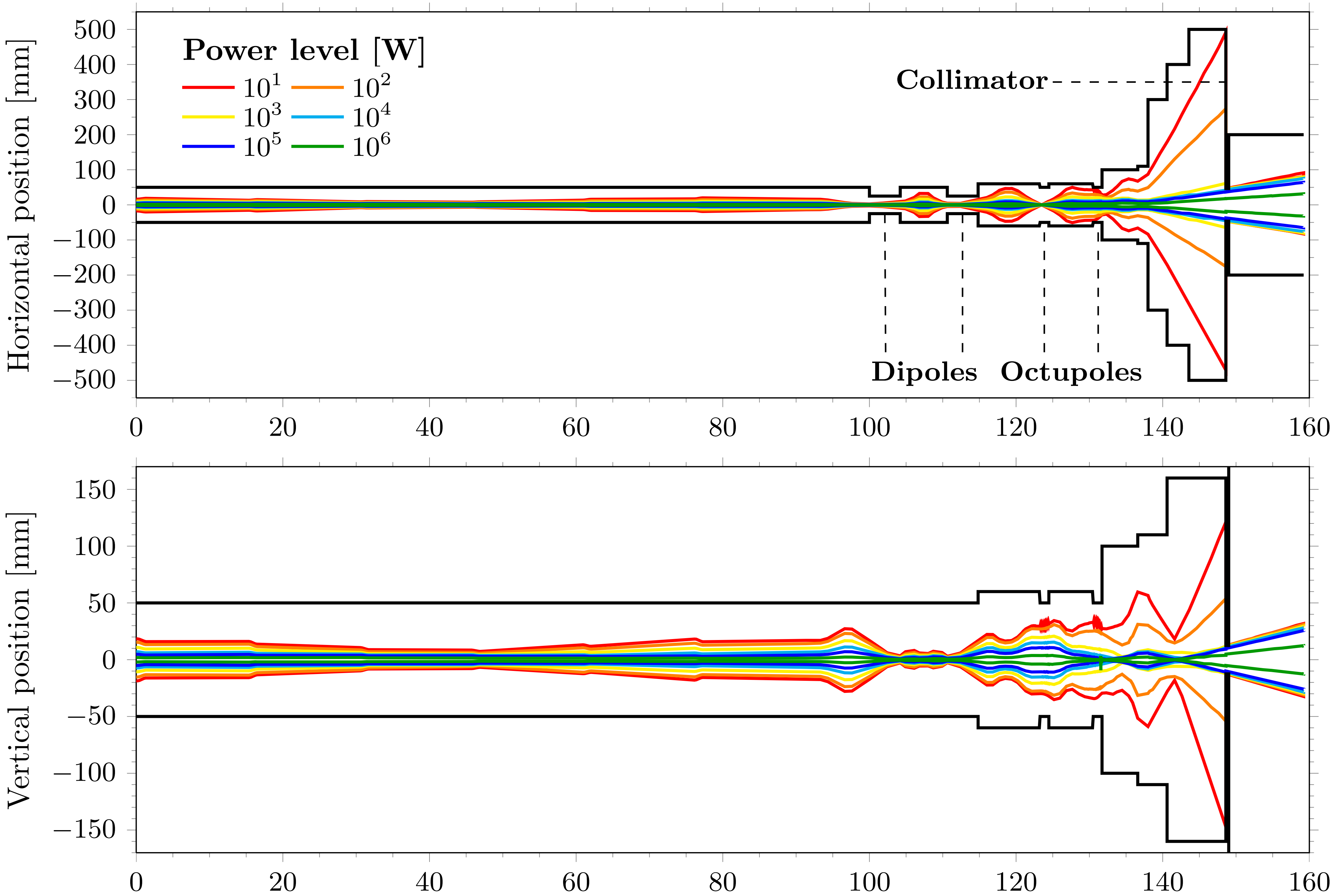




RMS beam sizes: horizontal blue, vertical red.

Vertical dispersion is matched through the vertical dog-leg.

Beam spreader



Proton density and beam power level contours along the HEBT.

A “rastering” method for beam-spreading is also under consideration.

Future opportunities

Accelerator

- Primary upgrade path is to operate at successively higher power (up to 7.5 MW or 10MW) while keeping the pulse length constant.
- An ambitious upgrade (20 years time?) would compress the long pulse in a storage ring, to match the cold neutron moderation time.

Target station

- One possibility involves the production of radioisotopes for the generation of radio-pharmaceuticals.
- Incremental improvements in the moderators will naturally occur.

Neutron instruments & support facilities

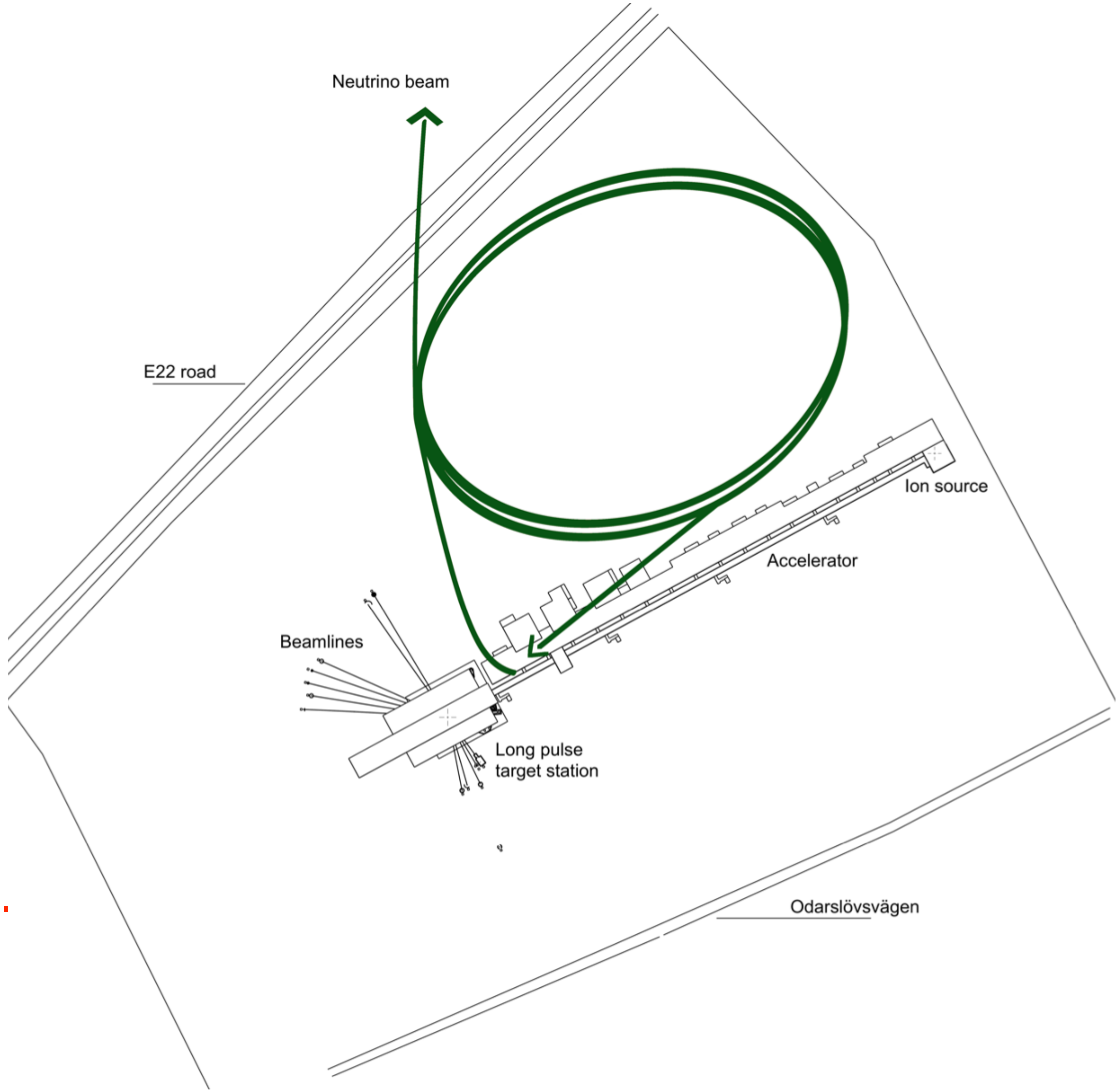
- Could increase the instrument portfolio from 22 to about 40, depending on demand & complementarity with other facilities.
- Additional user support facilities in collaboration with MAX IV could pay significant scientific dividends.

Neutrino beam upgrade?

Preliminary idea for a 5 MW compressor ring matching proton pulses to a 0.1 ms moderator.

4 stacked permanent magnet 2.5 GeV rings with 5 μs revolution time & a space charge tune shift less than 0.25.

Uppsala HEP folk, et al, advocate a neutrino beam to a northern mine.



Green cooling water

System	Cooling loop	Supply temp. [°C]	Return temp. [°C]	Total power [MW]
Accelerator	Low	17	34	4.3
	Medium	32	39	2.0
	High	47	$\boxed{78}$	$\boxed{8.4}$
	Sub-total			**14.7**
Target	Low	10	26	4.3
	Medium	30	$\boxed{67}$	$\boxed{3.2}$
	Sub-total			**7.5**
Cryoplant	Low	9	35	0.5
	Medium	32	60	3.2
	High	60	$\boxed{87}$	$\boxed{3.2}$
	Sub-total			**6.9**
Instruments	Low	12	27	**1.6**
Buildings	Low	12	27	4.0
	Medium	32	42	0.2
	High	47	77	−6.0
	Sub-total			**−1.8**
	Total estimated cooling demand			**28.9**

Estimated water cooling power demands in the 5 MW "beam on target" operating mode.

The Lund city district heating system prefers to buy (very) hot water, around 80 C.

Conclusion

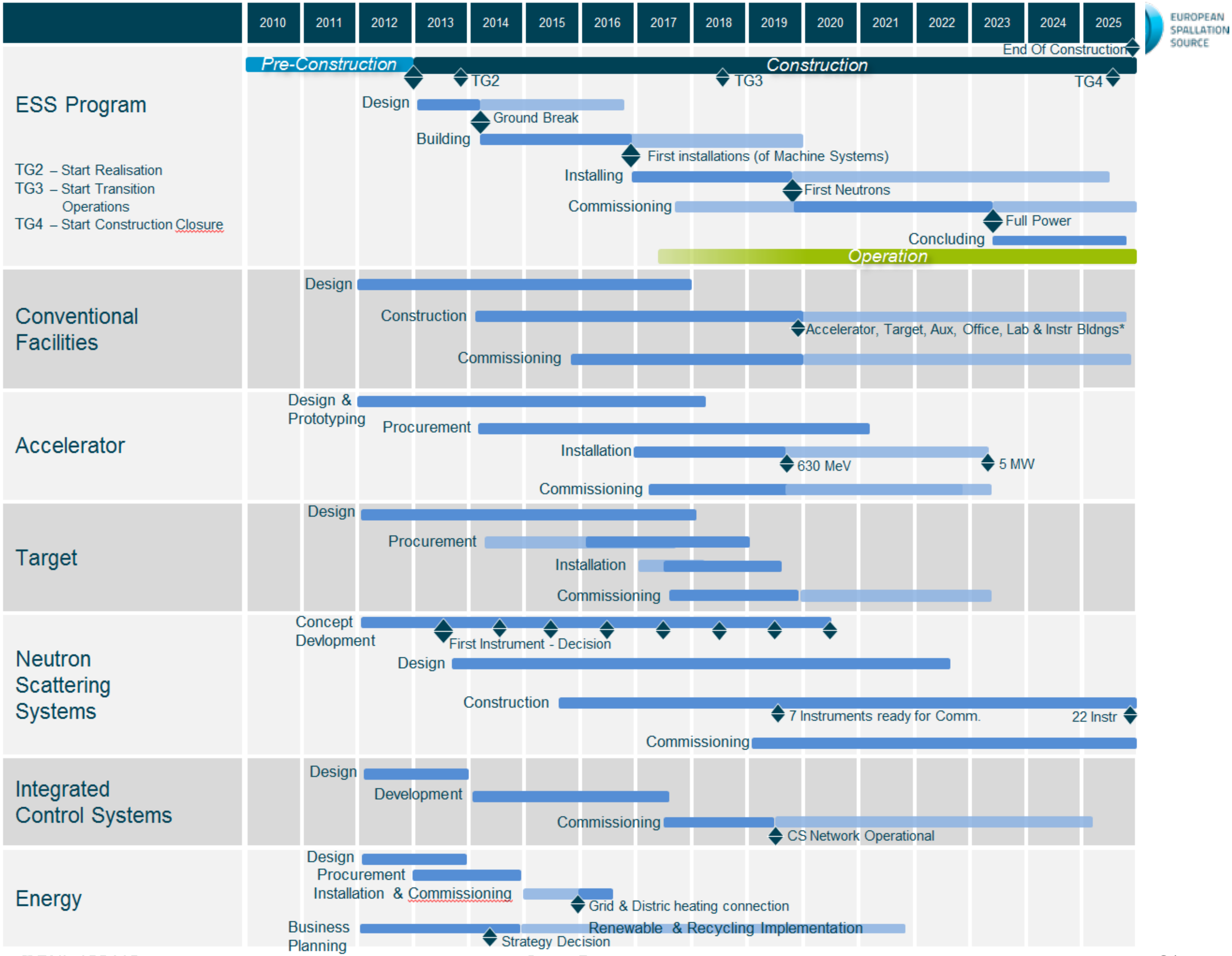
After more than 20 years work we are at the point where ESS construction of a 5 MW facility will begin, thanks to the dedication of countless hundreds, and perhaps thousands.

The Technical Design Report and a whole sheaf of documents together represent the current state of knowledge.

This body of knowledge has reached a certain state of maturity. It is, thanks to the nature of a scientific facility, incomplete. It will always be incomplete.

> *“If we wait for the moment when everything, absolutely everything is ready, we shall never begin.”*

said Ivan Turgenev. It is time to begin!



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EUROPEAN SPALLATION SOURCE
End Of Construction
Pre-Construction
Construction
TG2
TG3
TG4
ESS Program
Design
Ground Break
Building
First installations (of Machine Systems)
Installing
First Neutrons
Commissioning
Full Power
Concluding
Operation
TG2 – Start Realisation
TG3 – Start Transition Operations
TG4 – Start Construction Closure
Conventional Facilities
Design
Construction
Accelerator, Target, Aux, Office, Lab & Instr Bldngs*
Commissioning
Accelerator
Design & Prototyping
Procurement
Installation
630 MeV
5 MW
Commissioning
Target
Design
Procurement
Installation
Commissioning
Neutron Scattering Systems
Concept Devlopment
First Instrument - Decision
Design
Construction
7 Instruments ready for Comm.
22 Instr
Commissioning
Integrated Control Systems
Design
Development
Commissioning
CS Network Operational
Energy
Design
Procurement
Installation & Commissioning
Grid & Distric heating connection
Business Planning
Renewable & Recycling Implementation
Strategy Decision